ME 302L
CEE 370L

Materials Mechanics Laboratory Manual

By:

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Latest Revision
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Please forward corrections/suggestions to bj@me.unlv.edu

ME 302L Materials Mechanics Laboratory
CEE 370 L Engineering Mechanics of Deformable Bodies Lab
Spring 2011

Laboratory Manual
This is a downloadable pdf file with all information needed for this course.
There is no other textbook.

Lab Coordinator:
Dr. Brendan O'Toole, Ph.D.,
Associate Professor of Mechanical Engineering
SEB 2218, (702) 895 – 3885, bj@me.unlv.edu

ME Department Laboratory Director:
Mr. Jeff Markle, jmarkle@me.unlv.edu
TBE B-162, (702) 895 - 5597

Laboratory Sections and Instructors:
CEE 370L 001, TBE B-150, Wednesday 8:30 AM – 11:20 AM
Mohamed Zeidan, sabry.m.z@gmail.com

CEE 370L 002, TBE B-150, Thursday 8:30 AM – 11:20 AM
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Christopher Carron, carronc@unlv.nevada.edu

ME 302L 002, TBE B-150, Friday 4:00 PM – 6:45 PM
Muhammed Syful Islam, syful_islam@yahoo.com

All labs are performed in TBE B-150.
The Teaching Assistants (TA's) usually run the entire lab including:
instruction, grading, and evaluation of student performance.
Contact the laboratory coordinator if there is a problem that cannot be
resolved directly between the student and the TA.

[Vishay Measurements Group Strain Gage Website]
[Strain Gage Installation Manual]

ME 302 LAB SCHEDULE

Week	Dates	Lab Topics	Assignment Due Dates
1	1/17 – 1/21	First week of semester No Lab Classes	
2	1/24 – 1/28	Overview, Safety, Uncertainty Analysis Statistical Analysis	
3	1/31 – 2/4	Tensile Testing Data Reduction Overview	Homework 1A and 1B
4	2/7 – 2/11	Lab 1: Tensile Testing	
5	2/14 – 2/18	Lab 2: Poisson's Ratio	Lab 1
6	2/21 – 2/25	Lab 3: Torsion	Lab 2
7	2/28 – 3/4	Lab 4: Bending - Modulus of Elasticity	Lab 3
8	3/7 – 3/11	Lab 5: Strain Gage Application	Lab 4
9	3/14 – 3/18	(SPRING BREAK)	
10	3/21 – 3/25	Lab 5: Strain Gage Application	
11	3/28 – 4/1	Group Lab Projects	
12	4/4 – 4/8	Lab 6: Beam Deflections	Lab 5
13	4/11 – 4/15	Group Lab Projects	Lab 6
14	4/18 – 4/22	Lab 7: Column Loading	
15	4/25 – 4/29	Group Lab Projects	Lab 7
16	5/2 – 5/6	Group Lab Projects	
17	5/9 – 5/13	Finals Week	

ME 302 Lab Grading (CE 370 Grading may be different)

The grade for the lab will be divided as follows:

Individual Lab Reports & Homework:		**56 %**
HW 1a and 1b:	**7 %**	
Lab Report 1:	**7 %**	
Lab Report 2:	**7 %**	
Lab Report 3:	**7 %**	
Lab Report 4:	**7 %**	
Lab Report 5:	**7 %**	
Lab Report 6:	**7 %**	
Lab Report 7:	**7 %**	
Group Lab Report:		**15 %**
Quizzes:		**20 %**
Quiz 1 (Tensile Testing and Poisson's Ratio):	**5 %**	
Quiz 2 (Torsion & Bending):	**5 %**	
Quiz 3 (Strain Gage Application):	**5 %**	
Quiz 4 (Beam Deflection and Column Loading):	**5 %**	
Attendance/Participation:		**9 %**

Individual Lab Reports & Homework:

- Follow the format guidelines found later in this manual and directions from the laboratory instructor.
- ***Printed*** copies of your report are due on the assigned due date.
- You cannot turn in a lab report if you did not attend and participate in the lab.
- Each lab report and homework assignment is graded with a maximum score of 100 pts.
- Late Reports:
  - 10 points are deducted from your score for each week-day that the report is late.
  - For example, you will lose 50 points if the report is 1 week late.
  - Reports will not be accepted if they are more than 1 week late.

Group Lab Report:

- Each student will be a part of a group that plans and performs their own experiment.
- The lab TA must approve of all groups and projects before they are conducted.

Quizzes:

- Four closed book, short quizzes will be scheduled throughout the semester.

Attendance and Participation:

- The laboratory instructors will take attendance each week.
- They will also make note of enthusiastic participation, lack of participation, and/or leaving the lab early.
- They will assign a grade to each student at the end of the semester based on a combination of attendance and participation level in the class.

Excused Absences:

If you have a good reason to miss a lab, please contact your laboratory instructor ahead of time to make arrangements to make up the lab work.

All ME students must meet their faculty mentors at least once in each semester to avoid any hold in their registration. Please contact department for the name of the faculty mentor. When your faculty mentor is not available, you can contact ME Department for an advice.

ME 302L / CEE 370L
Materials Mechanics Laboratory

Lab Coordinator:

Dr. Brendan O'Toole, Ph.D.,
Associate Professor of Mechanical Engineering
TBE B-122, (702) 895 – 3885, bj@me.unlv.edu

The lab coordinator is responsible for:

- Planning the lab schedule each semester
- Coordinating the lab schedule with the lecture schedule as much as possible
- Revising and updating the laboratory manual
- Helping the Teaching Assistants (TA's) prepare for the labs
- Resolving conflicts between students and TA's (if necessary)

ME Department Laboratory Director:

Mr. Jeff Markle, jmarkle@me.unlv.edu

The lab director oversees all of the ME undergraduate laboratories and is responsible for:

- Maintenance of laboratory equipment (planned and emergency)
- Keeping track of laboratory supplies:
    - Strain gages and accessories
    - Test Samples
    - Soldering irons
- Keeping copies of equipment manuals
- Upgrading and installing new equipment
- Training students, staff, and faculty on new equipment as needed

Table of Contents

CHAPTER 1

OVERVIEW
OF
ME 302L (CEE 370L)

CLASS PROCEDURES
AND EXPECTATIONS

ME 302 (CEE 370L) Course Objectives

The primary objective for this course is to provide hands on experimental experience in characterizing mechanical properties of materials. Students will learn:

- Laboratory safety procedures
- Uncertainty analysis of data (error propagation)
- Statistical analysis of data
- Laboratory report writing skills
- Tensile Testing Procedures for finding: Young's Modulus, yield strength and strain, ultimate strength and strain, and failure strength and strain of metallic materials
- Procedure for determining Poisson's ratio of materials
- Flexure testing procedures for determining Young's modulus
- Torsion testing procedures for determining shear modulus
- Flexure test procedures for determining beam deflections
- Column compression procedures for investigating buckling behavior

Students will also perform a group project where they will propose and conduct their own laboratory experiment.

MEG 302L (CEE370L) Class Policies

PARTICIPATION

Attendance and active participation in the laboratory exercises are the only way to get the full learning experience offered by this class. You are expected to be available for the entire time that your lab is scheduled and part of your grade will be based on attendance. The Teaching Assistant assigned to your lab section will take attendance each week. You must contact the Teaching Assistant to discuss any excused absences and make-up labs if needed.

Most of the laboratory experiments will be performed in groups due to the limited amount of space and the number of test stations. Experimental data will be shared within your group but all group members must submit individual reports.

SAFETY PROCEDURES

You are responsible for following all College of Engineering Laboratory and Machine Shop Safety Rules as outlined in detail in Chapter 2 of this manual.

ASSIGNMENTS

You are responsible for following all College of Engineering Laboratory and Machine Shop Safety Rules as outlined in detail in Chapter 2 of this manual. Each student will submit one (1) homework assignment and six (6) lab reports. You might be working in groups in the lab but you will submit individual reports. In addition, there will be one (1) group laboratory project with one report submitted for the entire group.

Lab Reports

- Reports are due on the date indicated in the lab schedule (one week after completion of the laboratory)
- All lab reports are to be word processed, except the original data which will be included as an appendix.
- All graphs are to be computer generated. Provide a graph title, and label the axis and major graduations. Always provide units where applicable.
- Lab reports are to be structured as shown on the Laboratory Report Contents Sheet.
- All equations, graphs, tables, and figures are to be numbered, with the appropriate "call-out" reference within the text. Also provide a Table of Graphs and Figures immediately following the Table of Contents if the report has many figures.
- The reports will be graded on format, content, and grammar, so be sure you proofread (and spell check) your reports.

1. Most reports should include an abstract, experimental procedure, results, analysis of results, and conclusions.
2. Raw data should be included as an appendix if it can be formatted within a few pages. If you have many pages of raw data in a computer file, do not append it to the report. Keep it somewhere safe for the semester and be prepared to send a copy or bring a copy to a classmate, teaching assistant, or other instructor if needed.
3. The analysis of results should include uncertainty analysis of your experimental measurements, statistical analysis of your data if 3 or more data points are available, and a comparison of experimentally obtained properties with expected results.

- Late lab reports are accepted at a penalty of 10% per day (excluding Saturday & Sunday). Reports will not be accepted more than one week late.

Group Laboratory Project

- All students will participate in a Laboratory group project. The objective of this project is to provide an opportunity for all students to participate in the process of designing an experiment. All topics must be approved by the Teaching Assistants. The groups must have between 4 and 5 members. You cannot work alone; you must work in a group.
- The project should be a simple experiment that can be performed in 1-2 hours. **The preparation, design of the experiment, gathering of materials, and selection of test fixtures may take longer.** You must submit a brief description of your experimental plan to your TA for approval before conducting the experiment. The plan should clearly state, the materials you plan to use, the fixtures needed, the test procedure, and your plan for analyzing the data.
- Lab projects must make use of the principles learned in ME 302 and must involve material testing using knowledge obtained in ME 302L.
- The project will require one written report for each group.
- Projects must be performed and reports submitted by **the last day of regular classes in the semester.**

Laboratory Report Contents

All laboratory reports (except Lab # 1) **must** consist of the following:

Title Page (Example at the end of this section)

Table of Contents

List of Figures and List of Tables

- Necessary if the report has more than 5 figures or 5 tables..

Abstract

- State the lab objectives.
- Provide a brief summary of the results.

Introduction

- Provide background information regarding the experiment.
- Include the application of the experiment to theory.
- Indicate what the anticipated results of the experiment are, if known. In most cases, theoretical values (from the tables in the book) are the anticipated results.

Equations

- Engineering students need to know how to include computer generated equations in reports. Use Microsoft equation editor for generating equations in your lab reports.
    - The equation editor can be accessed by selecting the "Insert" tab from the menu bar, then select "Object", then select "Microsoft Equation". Equation symbols are selected from the various menus.

Experimental Procedure

- Describe the specimens tested (type of material, physical dimensions, etc.). **Do not** say things like, "these were the same specimens used in Lab # 2." Each lab report is a separate entity, and the specimens must be fully described each time.
- Identify the instruments used, including manufacturer and model number.
- Provide a **detailed** description of the laboratory procedure used. **Do not** simply repeat the procedure that I give to you; expand on it by explaining why something is done or how something is done.
- Include a sketch of the experiment setup. This may be hand drawn, but be neat.

Results

- Identify the equations used to obtain the results.
- Present the results.
- Provide appropriate plots, graphs, and tables.
- Make sure the report "flows" from the beginning to the end of the experiment; don't present final results prior to intermediate calculations.

Analysis of Results
Calculate % error with the formula:

$$\% \text{ Error} = \frac{(\text{Expected Results - Experimental Results})}{\text{Expected Results}} \otimes 100$$

where, .

the expected results are found from tabulated data in a reliable source (textbook)

or the expected results are determined from theoretical predictions.

- Indicate sources of error. Do not just say, "human error." Be specific.
- **Specify the uncertainty of your calculations using methods described in the Statistics Lab.**
- **Specify the statistical variation (mean and standard deviation) of your results if 3 or more data points are available.**

Conclusions
- State what the results mean.
- Was the experimental method used a valid one? Explain why or why not.
- Did you accomplish the objectives of the lab? This is not a "yes/no" question. You must explain how the objectives were or were not met.
- Remember that you may not always get the "proper results" even though you followed the procedure and performed the experiment properly.

Appendices
- Provide all raw data collected in the lab (In other words, your original data sheet. This is hand written, and will not be graded for neatness). ***DATA IS NEVER TO BE ALTERED.***
- Provide a list of references.

Laboratory Number

Laboratory Title

Prepared For:

"Your Laboratory TA", ME 302L

Department of Mechanical Engineering

University of Nevada, Las Vegas

Prepared By:

Your Name

Your Group Members

Date Laboratory Performed:

Date Submitted:

CHAPTER 2

GENERAL LABORATORY SAFETY PROCEDURES

University of Nevada Las Vegas

Howard R. Hughes College of Engineering

MACHINE SHOP AND LABORATORY POLICIES AND PROCEDURES

General Safety Guidelines

The following is not intended to be exhaustive, nor the final word about shop/laboratory safety, shop procedures and policies. It is up to you, the individual, to be responsible for your safety and to follow sound, sensible safety guidelines. We encourage and are open to your suggestions and comments.

The purpose of this document is to familiarize all students/faculty/staff, who have a need to work in the labs or shop, with safe operating procedures. OSHA, the State of Nevada (NIOSH) and UNLV all require, by law, that we include safety training, as part of your lab class instructions. Everyone that has a need to use chemicals will receive "HAZMAT" (hazardous materials) training from the UNLV environmental health and safety office.

Since it is possible for anyone to lose their limbs, eyes, or life due to an accident, simple carelessness or even failing to use an inexpensive piece of safety apparel, UNLV Engineering College has implemented these rules of conduct for all persons needing to use the shops and/or labs. As soon as a new safety training document is updated or completed, every student will receive a copy. Inasmuch as safety is everyone's responsibility, take the extra few seconds to equip yourself with the proper safety apparel to do the job correctly, you may be thankful the rest of your life that you did. Think about having to live the rest of your life knowing that you could have prevented your own or someone else's dismemberment because you didn't do, say something, or think about safety.

Although we are not 100% configured in accordance with all ADA laws covering disabled persons, we can make nearly all adjustments that are required to accommodate any person on a case-by-case need. If you have a documented disability, you are encouraged to contact the Disability Resource Center for assistance with your academic accommodations in the Reynolds Student Services complex in room 137. Their phone number is 895-0866

BASIC SHOP AND LABORATORY SAFETY RULES

These basic rules have been drafted because many of these infractions have been encountered here at UNLV and have resulted in an injury of some kind and even the loss of a life. We must strive to assure that the loss of life or limb never happens again. These rules are not flexible and must be followed at all times, no exceptions, exemptions and no excuses and the penalties for flagrant violations are inflexible and could impede your graduation efforts.

1. No horseplay ever.
2. No drugs or alcohol ever. (24 hours a day 7 days a week)
3. There must be at least two persons in the shop or lab when working.
4. Be considerate of the others working in your area. Keep noise to a minimum as other people working in your area may be trying to conduct an experiment and don't want to be distracted by other people having a “party”.
5. Do not approach or touch any machine operator from behind while any equipment is in operation. If you must get their attention, first call to them from a distance so they may switch the machine off before being distracted by conversation. When talking with another person, always shut off all moving or rotating equipment.
6. Dress appropriately for shop or lab work. Loose and/or baggy clothing and long sleeve shirts are not to be worn when operating machinery. Keep in mind that some of the equipment turns at a high rate of speed and may catch your clothes and pull you into the machine. Dismemberment and death has resulted in past instances.
7. If you have long hair, long beards or long and dangling neck chains and they are allowed to dangle down into what ever you are working on, they must be removed, restrained or tied back, somehow, so they will not reduce the scope of your vision and or be caught in the equipment. Also, bracelets and ear rings present a real hazard. If they get entangled, serious injury can result. The most common danger comes from rings getting snagged in rotating equipment and ripping the finger or entire hand off. Sometimes a ring becomes an electrical path, causing electrocution and death.
8. Only approved shoes may be worn in the shops and labs. No "shower shoes" and no open toe shoes. If you are working with heavy steels, consider purchasing steel toe safety shoes.
9. Shorts may not be worn in shops and labs. We suggest that you bring a pair of pants or slacks and pull them on over your shorts before class or while working in the shops and labs.
10. Materials and equipment may not be removed from the buildings of the Engineering College without proper authorization. Nevada state laws require a written receipt, signed by the person responsible for inventory of the items, be issued to and accompany the person removing the property from the building.
12. After using any air operated tool, disconnect the air line before setting the tool down because it may twist or roll and by chance, turn itself on.
13. Never use the air line to blow dust or dirt off your clothes or body, as there is enough force to penetrate the skin and cause serious injury. Be aware that high concentrations of dust in the air can cause explosions.
14. If you have a key to a lab or shop area, you may not loan that key to anyone or make a copy of it. If someone needs access to a lab or shop, they must go to the Professor in charge of that lab or the Department office for authorization to gain access. People holding keys that they have not been issued should refer to the Nevada Revised Statutes to review the penalties for possession of burglary tools - it is a felony which carries the possibility of a $10,000 dollar fine and up to five years in jail.
15. If you detect any equipment that appears to not function properly, you must not use it. Notify one of the shop technicians or the teaching assistant and/or bring the tool to the shop, where we will repair it or we will replace it, as needed.

16. Spilled liquids, chemicals or glass will be cleaned up immediately, in accordance with UNLV, OSHA and HAZMAT regulations. Notify shop staff at once at 4285 or 4300.
17. Any combustible or flammable materials (saw dust, chemicals, used rags, etc.) must be stored and/or handled and disposed of in accordance with OSHA, HAZMAT and UNLV regulations.
18. Because we store propane cylinders and our hazardous waste storage is located in the yard/work area on the north side of the "B" building, smoking is not permitted anywhere in that work/storage area.
19. Because the fenced area behind the "B" building is a work and storage area, do not use that area as an entrance into the building. Do not use that way as an exit because the gate may be locked.
20. Never stand on the top step of a step ladder. Never use a chair instead of a ladder. Never stack a ladder on top of any other objects to reach higher.
21. When you borrow or check out a tool item from the shop, return it. If you open something, close it. If you break something, try to fix it if you are qualified or let us know so we can. If you turn something on, turn it off. If you take something out of a cabinet, put it back where it belongs. Take the extra few seconds to be responsible for what you do and help out by doing things correctly.
22. Whenever working with tools overhead, there is a danger of objects falling into your eyes or hitting someone below that is unaware of you working above. Therefore you must use safety goggles during that time you are working overhead and when working in an elevated position, you must make sure that no people can pass beneath you and get hit with a dropped tool or other falling objects.
23. Only authorized and trained persons are to use the machine shop equipment. Any person operating any equipment which they have not been properly "checked out" on will be removed from that laboratory or the shops. MEG-130 is required before anyone is authorized to operate the machinery. As long as a person can demonstrate average competence, then MEG-130 is not required. Contact a management assistant in the Mechanical Engineering Dept. office to sign up for that class.
24. Before operating any laboratory equipment, be sure you have been "checked out" by the TA's or the shop supervisors before you begin work in order to be sure that you know how to operate it, to make sure that it works properly and to make sure that you have the supplies that you need.
25. When you finish working in a lab or on your project for the day, you must make sure that the lab or shop equipment is returned to the proper storage place and that the apparatus is complete. Also, advise the shop staff if/when supplies are nearly depleted so we know the status and reorder what is needed. Leave the room in order and clean.
26. Any person who will handle hazardous materials or chemicals must receive "HAZMAT" training from the UNLV Environmental Health and Safety office. This is especially mandatory for any "TA" who will teach or supervise a class where the handling of these chemicals or substances will take place. Call 4226 to arrange to get this training. UNLV requires that you take this one hour course successfully before you will be allowed to work with any hazardous substance in the shops and labs of the Engineering College.
27. Be aware that many chemical bottles are color coded along with their caps. Never switch chemical bottle caps because it may set off a violent reaction and cause serious injury from the chemical and flying glass. All chemical containers must be properly labeled and accounted for. When labeling a container, obtain the appropriate warning label from the shop technicians.
28. When transporting any chemical within the building, the appropriate measures must be taken according to the OSHA regulations. Anyone involved with chemical transportation must read the set of regulations located in the technician's office.
29. In the event of a chemical spill, since you have already seen and understood the MSDS you should be immediately able to determine the seriousness of the spill. If an evacuation is warranted, actuate the fire alarms and call 911 to report the incident. If the spill is not that serious or you can't decide what the level of seriousness is, then immediately contact one of the technicians. We have had emergency response training and we also have a "spill cart" to clean up many small spills.

30. When working with chemicals, don't breathe in the vapors and always wear the proper protective clothing to keep solvents, acids and other chemicals off your skin. This may sound silly to you, but wear safety goggles and “keep your mouth shut” when pouring chemicals because they may splash into your eyes or mouth and then in is ingested into your system, either injuring or killing you.
31. Many chemicals, which are considered safe for home use, <u>require</u> an MSDS when it is in a work place. This may seem absurd, however, it is the law and we must comply, so do not bring any chemical, solvent, lubrication oil, paint, etc., on to UNLV campus without prior approval from the Department Chair or the department technician. All chemical purchases by purchase order must go through the campus Health & Safety Office to insure that everything meets with UNLV policy. When in doubt, ask. Don’t be afraid to ask and please, don’t try to sneak “stuff” in.
32. The proper disposal of waste chemicals, materials, compounds and paint products is mandated by law. Never dump a chemical into the drains, toilets or sinks because of possible chemical reactions and the contamination of the ground water. The empty containers are also disposed of in an approved manor. Bring any and all of those empty containers and waste chemicals to the shop technicians for disposal. Never mix or dilute the waste products. Let us handle and arrange for their disposal.
33. All shops and labs are equipped with the basic safety equipment such as a fire extinguisher, eye wash station, a fire blanket, a phone and hazardous materials Right to Know safety information. It is <u>**highly recommended**</u> that you take the time required to familiarize yourself with the emergency instructions and to read the MSDS information papers to see how it could affect your life.
34. Some chemicals <u>require</u> the use of a breathing apparatus or a special filter element. It is <u>**your personal responsibility**</u> to read the MSDS to determine exactly what is the required practice in order to safely use that chemical.
35. If your laboratory requires the use and handling of hazardous materials and chemicals, there are many specific guidelines that must be followed, from the ordering process, receiving, handling, storage, use, dilution, clean-up all the way through to the proper disposal. See the shop technician or your supervisor for more information.
36. “NO FOOD OR DRINK” signs are on all the classrooms, laboratories and shop entrance doors. The policy with reference to the use of a microwave ovens and refrigerators for food storage, food preparation, in the shops, classrooms or labs is as follows; “Food is not to be stored, prepared or eaten in the shop, classrooms and labs”. This practice is especially dangerous and will be strictly enforced when there are hazardous materials or chemicals stored or used in the same room.
37. When using any tool that may produce a chip or fragment as a result of using that tool, i.e. drill, lathe, mill, saw, chisel, hammer, cutting wheel, grinder, sander, etc., an OSHA approved (Z-87 inscribed) face shield and/or safety goggles must be worn.
38. When installing any item that will be placed under any stress, tension, pressure, or strain while it is being tested, used, operated or de-installed, one must wear the appropriate safety equipment, such as, goggles and/or face shield. Springs are the worst, as they fly off unpredictably.
39. If your laboratory requires the use of compressed gas cylinders, there are special procedures that are required for placement and handling. See the shop technicians or your supervisor for more details.
40. Equipment or tools may not be used for working on personal projects or property.
41. If someone is in the shop area after hours and not in compliance of the rules, and if they are not authorized or qualified to use that equipment, we WILL turn the matter over to the appropriate Department Chairperson or the UNLV Police Department.
42. When working in a laboratory, students should not have their friends over to talk or meet them for lunch, etc. as this causes a lot of needless traffic and noise in the laboratory and is an unsought distraction to someone trying to study.
43. The policy for room access is that if you need access to a lab or room, then you must go to your Department office and someone there will unlock the doors to let you in. They will log opening

times, who entered and closing times. This will create a record which will be available to the police department, if needed.

44. If you have a key to a lab or shop area, you may not loan that key to anyone or make a copy of it. If someone needs access to a lab or shop, they must go to the Professor in charge of that lab or the Department office for authorization to gain access. People holding keys that they have not been issued should reefer to the Nevada Revised Statutes to review the penalties for possession of burglary tools - it is a felony which carries the possibility of a $10,000 dollar fine and up to five years in jail.
45. OSHA being a Federally mandated organization is backed by federal laws that has some “teeth” in it. Their minimum fines depend upon the infraction and they range from the $1000 up to $???,???.00 per incident. If the violation is determined to be a willful, the fine could be as high as $70,000. Therefore it’s practical to learn to function within these regulations rather than battling with them.
46. An important department policy is that all labs and classes must have a sign in log. (roll call or whatever you want to call it) reason: if for some reason anything happens and we are required to evacuate the building, we will know who was in class or not. Upon evacuation, the professor or TA in charge of the class must meet at a pre-designated location and take another roll call. This way we will know when everyone is accounted for.
47. Because people may get cuts and abrasions and/or bleed when working with metals or other equipment, it is important that everyone be aware of blood borne pathogens and the potential harm that may arise if you touch another persons’ blood or bodily fluids.

    The basic rule for this is:
    “***If it’s wet and you don’t <u>know</u> where it came from, don’t touch it***”.

    It is suggested that if you have any medical problems such as convulsions, epilepsy, paroxysms, seizures, or blood borne diseases, etc. which could be potentially dangerous to yourself and/or others safety, that you advise the shop staff as to what your particular situation may entail. This information will be held completely confidential.
48. Your concerns and any suggestions about safety related issues are always encouraged and welcomed. If you have any questions about anything, you are obligated to ask the Professors, shop technicians, TA’s, or office staff who will assist in resolving any challenge. We are here to help you with your education and lay the ground work for your chosen profession. We can’t help if you don’t seek our assistance and if we don't know what your concerns are.

MATERIAL SAFETY DATA SHEET & HAZARDOUS MATERIALS

The most important document that you should seek out is the MSDS (material safety data sheets). The MSDS is a document which is prepared by the original manufacturer of products or chemicals which informs the public of the any known hazards of the chemical. Attached is an MSDS for Acetone. Read it carefully so you can recognize the various health and safety categories that it provides information on. Note the safe handling procedures and the breathing filtration requirements. There is a section in every MSDS that explains what personal protective equipment is required for safe handling.

All shops and labs are equipped with basic safety equipment and hazardous materials right to know (RTK) and other safety information. It is required that you read the MSDS sheet on the chemical that you are about to use, or order, to know how it could effect the rest of your life and to be sure that all the required safety measures are on hand and in effect to allow usage of that chemical or substance. The goal here is to be able to use the least toxic chemical for what ever purpose you're using it for. If you need a certain item, then get it, but don't get it to have it around "in case" you want to use it.

Each shop and lab has different safety areas of concern that will be covered with you as needed or on an individual basis. Also, our shops and labs are not completely in compliance with the laws covering disabled persons, because much of this equipment was designed long ago and the ADA requirements were not even thought of then. The replacement or remodeling the equipment with the proper accessibility, is not in the budget, and in some cases, is nearly cost prohibitive. We will make whatever adjustments are necessary to accommodate the challenged person on a case by case basis. Your TA will cover the safety aspects of the lab you're in and the shop technicians will cover the equipment that you may need to use in the shop.

If you have a documented disability and you require assistance, we suggest that you contact the Disability Resource Center, ASAP for co-ordination of your academic accommodations. The "DRC" is located in the Reynolds student services complex in room 137. Their phone number is 895-0866 (TDD 895-0652).

SHOP SUPPLIES

We will make every effort to keep the shops supplied with everything that you need to accomplish your tasks. In order for us to accomplish that, we need your input. Each senior design student and all the TA's will meet with the shop staff to discuss your up-coming projects to assure that we have the supplies on hand, or get them ordered. If you don't come to discuss your project in advance of beginning to make it, don't expect to have all of the parts on hand that you need. Ordering takes time. For the most part things are first come first served, however it is requested and preferred that you make an appointment so your time will not be wasted.

Mechanical Engineering students should call 895-4285 to talk to Mr. Kevin Nelson, (kevinn2@cox.net) who is the technician for Mechanical Engineering Department and Civil Engineering students call 895-4300 to talk to Allen Sampson, (sampson@ce.unlv.edu) who is the technician for Civil and Environmental Engineering Department in order to make an appointment or arrangements to discuss your needs. The shop hours are Monday through Friday 8:00 am to 5:00 PM and on Saturday, Sunday and holidays the shop is closed.

Anything that you remove from the shops or storeroom must be signed out on the clipboards hanging at each door. Before operating any equipment, be sure you have been "checked out" by the shop supervisors before you begin work in order to be sure that you know how to operate it, make sure that it works properly and make sure that you have the supplies that you need. Also, when you finish working in a lab or on your project for the day, you must make sure that the lab equipment is returned to the proper storage place and that any of the tools you used are complete and operational, make sure that the room is in order and you must clean up after yourself daily, no exceptions, and then advise a supervisor if supplies are depleted so we will know the status and be able to reorder supplies on a timely basis.

As a last and additional note, if you have any disorder such as epilepsy, narcolepsy, sudden loss of balance, etc. we suggest that you inform the TA or a shop supervisor so we can be of help in the event of an episode. In the past, one victim of epilepsy received a very expensive and humiliating ambulance ride because he didn't confide in us about his condition. Any personal information will be held in strict confidence if you request us to do so.

EMERGENCY PROCEDURES

(MEDICAL OR FIRE)

CALL 911 IMMEDIATELY

then give them:

A. YOUR NAME,
B. BUILDING, (THOMAS BEAM ENGINEERING)
C. ROOM NUMBER (ROOM TBE-B-_ _ _)
D. TELL THEM CALMLY AND CLEARLY WHAT THE EMERGENCY IS.
E. FOLLOW THEIR DIRECTIONS.

If there is a need to evacuate the building, pull the fire alarm and exit the building and meet at the designated meeting place. The designated location for everyone to meet immediately after exiting the building during an emergency is on the sidewalk near the parking lot and just east of the loading ramp leading to the back entrance to the Artemus W. Ham Concert Hall. Make sure that the instructor or TA writes your name on a list before you depart the area.

If you are injured and do not need 911 assistance, immediately notify your supervisor and the department's Management Assistant and follow their standard procedures. If neither of those are immediately available, notify any professor of any shop staff.

IMPORTANT PHONE NUMBERS

UNLV PUBLIC SAFETY (POLICE)
EMERGENCY # 911 NOTE - Do not dial "O" first for on campus emergencies.
NON-EMERGENCY 895-3668

UNLV ENVIRONMENTAL HEALTH AND SAFETY

Ms. Becky Delacruz 895-4226 Occupational Safety Technician (OSHA) bdelacruz@ccmail.nevada.edu

Mr. Ed Gannon 895-1791 Fire Safety Compliance gannon@ccmai.nevada.edu

Mr. Courtney Kerr 895-42265 HAZMAT Compliance courtney kerr/UNLV@UNLV

SHOP SUPERVISORS

MECHANICAL ENGINEERING DEPARTMENT OFFICE 895-1331
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MEG 302L Materials Mechanics

Laboratory Safety & Procedures

I ____(Name) have read and understood the laboratory safety procedures and policies. I am responsible for following these procedures while in the laboratories.

______________________________ __________
(Signature) (Date)

CHAPTER 3

STATISTICAL ANALYSIS

AND

UNCERTAINTY ANALYSIS

Chapter 3:
Statistical Analysis and Uncertainty Analysis

****

Objectives

Chapter 3 will cover some topics from statistics and uncertainty analysis. The statistical analysis will be used when data is obtained for multiple specimens that are made from the same material and tested under the same conditions. The statistical analysis helps determine the average values and degree of consistency from specimen to specimen. The uncertainty analysis determines the degree of confidence in the reported experimental values. At the conclusion of this lab, you should be able to:

- Calculate the arithmetic mean, median, and mode of a data set.
- Identify the range of a set of data.
- Calculate the variance and standard deviation of a data set.
- Perform a simple linear regression on a data set.
- Create a plot showing the data set and the linear regression lines on the same plot.
- Determine the uncertainty in reported experimental data by calculating the error propagation from measured variables.

All required materials will be handed out and discussed in class, so no background preparation is required before this lab.

****

3A: Statistics

Statistics is the science of collection, classifying, and interpreting information based on the number of samples. The primary purpose of using statistics when reporting laboratory data is to determine the average value and repeatability of the experimental results between multiple specimens. The minimum number of specimens need to conduct statistical analysis is three.

Data Description

Data may be described in a variety of ways. Perhaps the most efficient manner of presenting data includes the use of graphics; displaying the data as a point plot or histogram. In addition, the data itself is given characteristic numbers to describe the data distribution. Some common numbers given to data are:

1. Arithmetic Mean

The arithmetic mean is the average of a set of data, and is calculated by:

$$\mu = \frac{\sum x}{n}$$, where *n* is the number of data points.

2. Median

The median is the middle value of a data set when the data set is sorted from smallest to highest value.

3. Mode

The mode is the value with the highest frequency of occurrence.

4. Range

The range is the difference between the highest and lowest values in a data set.

5. Variance (σ^2)

The variance is a measure of central tendency (a measure of the tendency of the data to group about a certain value), and is determined by:

$$\sigma^2 = \frac{\sum (x-\mu)^2}{n} \text{ for a population or } \sigma^2 = \frac{\sum (x-\mu)^2}{n-1} \text{ for a sample.}$$

Use the first equation (for a population) is the entire set (or population) of data is used to calculate the variance. Use the second equation if only part of the data set is used to calculate the variance.

6. Standard Deviation (σ)

The standard deviation is the most commonly used measure of central tendency, and is defined as the square root of the variance.

Simple Linear Regression

Linear regression is used when the relationship between variables must be determined. Linear regression suggests that two quantities are related, such that increasing (or decreasing) the x component increases (or decreases) the y component. In a simple linear regression model, we attempt to fit our data to a line described by:

$$y = mx + b$$

To obtain a best fit model, we will use the least square method, which minimizes the Sum of the Squared Errors (SSE) to the best fit line. In this method, the best fit line is given by:

$$y = b_1 x + b_0, \quad \text{where} \quad b_1 = \frac{n\sum(x_i y_i) - \sum x_i \sum y_i}{n\sum(x_i^2) - \left(\sum x_i\right)^2} \quad \text{and} \quad b_0 = \bar{y} - b_1 \bar{x}$$

Also: $\bar{x}$ = the arithmetic mean of x values and $\bar{y}$ = the arithmetic mean of y values.

Coefficient of Correlation (r)

The Coefficient of Correlation is a measure of how well the data fits your model, with $r = 1$ being a perfect fit, and $r = 0$ being no correlation. The Coefficient of Correlation is calculated by:

$$r = \frac{n\sum(x_i y_i) - \sum x_i \sum y_i}{\sqrt{\left[n\sum(x_i^2) - \left(\sum x_i\right)^2\right]\left[n\sum(y_i^2) - \left(\sum y_i\right)^2\right]}}$$

The coefficient of determination is defined as r^2.

Statistical Analysis – Class Example

Ten production lines were surveyed to determine productivity (x) related to the number of workers (y). The survey showed:

Line	Production units (y)	# of workers (x)
1	179	24
2	413	53
3	95	16
4	121	21
5	352	50
6	61	14
7	121	20
8	240	37
9	79	14
10	163	22

Perform the following Statistical Analyses (In-Class Examples):

Find the median production.
Find the arithmetic mean of production.
Find the mode of production.
Find the range of production.
Find the variance and standard deviation of production.
Perform a least squares regression of y on x.
Plot both the raw data and the linear regression equation on the same graph. Label all axes.
Find the coefficient of correlation.
Find the coefficient of determination.
Determine the estimated production on a line with 38 workers.

Statistical Analysis – Class Example

Resort the data in the tables from least number of workers to most numbers of workers.

Line	Production units (y)	# of workers (x)
6	61	14
9	79	14
3	95	16
7	121	20
4	121	21
10	163	22
1	179	24
8	240	37
5	352	50
2	413	53

Find the median production.
The median is the middle value of the production when sorted from lowest to highest. There is an even number of production data points so we take the average of the 5^{th} and 6^{th} value.

The median value of production is (121 + 163)/2 = 142.

Find the arithmetic mean of production.
The arithmetic mean of production is the sum of all production values (sum = 1824) divided by the number of production values (10).

The arithmetic mean of production = 182.4.

Find the mode of production.
The mode is the value that occurs most often.

The mode of production is 121.

Find the range of production.
The range is the difference between the highest value and the lowest value.

The range of production is equal to 413 – 61 = 352.

Find the variance and standard deviation of production.

It is easy to do this with a program like MS Excel or other math program. These math programs have built in functions to determine statistical properties. You should do the calculations yourself but you may also use the built-in functions for comparison. Another column was added to the previous table. $(y-\mu)^2$ was calculated for each production value in this column; μ is the arithmetic mean, which was calculated previously. The sum of all these values was determined and the variance was found by dividing by n (10). "n" was used instead of "n-1" because the entire population of data was used to determine variance.

The calculations lead to a variance (σ^2) value of 12,625 and a standard deviation (σ) of 112. The same numbers were determine using the built in MS Excel functions VARP() for "variance of a population" and STDEVP() for "standard deviation of a population".

Line	Production units (y)	# of workers (x)	$(y-\mu)^2$
6	61	14	14738
9	79	14	10692
3	95	16	7639
7	121	20	3770
4	121	21	3770
10	163	22	376
1	179	24	12
8	240	37	3318
5	352	50	28764
2	413	53	53176
sum	1824	271	126254
mean (μ)	182.4	27.1	
range	352		
Variance (n) (my calcs)			12625
Stand. Dev. (n) (my calcs)			112
Variance (Excel)	12625		
Standard dev (Excel)	112		

Perform a least squares regression of y on x.
Recall that the best fit line for the data is defined as:

$$y = b_1 x + b_0 , \quad \text{where} \quad b_1 = \frac{n\sum(x_i y_i) - \sum x_i \sum y_i}{n\sum(x_i^2) - \left(\sum x_i\right)^2} \quad \text{and} \quad b_0 = \bar{y} - b_1 \bar{x}$$

Also: $\bar{x}$ = the arithmetic mean of x values and $\bar{y}$ = the arithmetic mean of y values.

Add two more columns to the previous table to calculate the necessary terms in the b_1 coefficient as shown below.

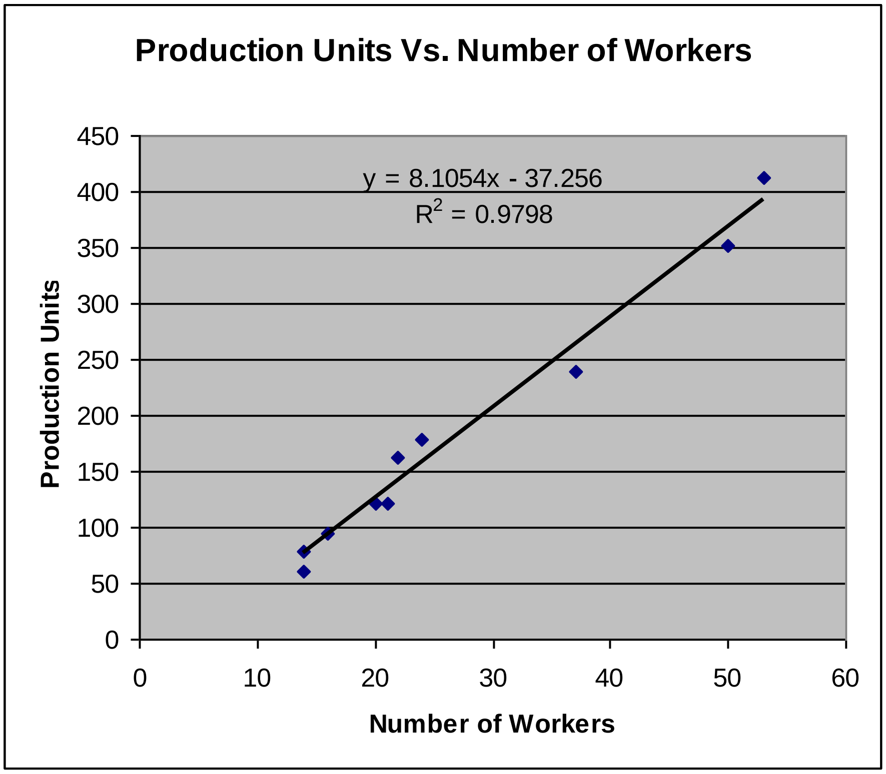
Line	Production units (y)	# of workers (x)	$(y-\mu)^2$	x*y	x^2
6	61	14	14738	854	196
9	79	14	10692	1106	196
3	95	16	7639	1520	256
7	121	20	3770	2420	400
4	121	21	3770	2541	441
10	163	22	376	3586	484
1	179	24	12	4296	576
8	240	37	3318	8880	1369
5	352	50	28764	17600	2500
2	413	53	53176	21889	2809
number of data points, n	10				
sum	1824	271	126254	64692	9227
mean (μ)	182.4	27.1			
range	352				
Variance (n) (my calcs)			12625		
Stand. Dev. (n) (my calcs)			112		
Variance (Excel)	12625				
Standard dev (Excel)	112				

Sum(x) * Sum(y)	494304
n * Sum (x*x)	92270
$[\text{Sum (x)}]^2$	73441
n * Sum(x) * Sum (y)	646920
b1	8.11
b0	-37.3

So the best fit equation of the line to fit the data is: ***y = (8.11)x – 37.3***

Plot both the raw data and the linear regression equation on the same graph. Label all axes.

MS Excel was used to create the graph of raw data. A scatter plot was first created and then a linear trendline was added with the equation and coefficient of determination displayed. The coefficients in the MS Excel equation are equal to the ones calculated on the last page.



Find the coefficient of correlation.

The Coefficient of Correlation is calculated by: $r = \dfrac{n\sum(x_i y_i) - \sum x_i \sum y_i}{\sqrt{\left[n\sum(x_i^2) - \left(\sum x_i\right)^2\right]\left[n\sum(y_i^2) - \left(\sum y_i\right)^2\right]}}$

A few more lines and columns are added to the MS Excel table in order to calculate r and r^2, which are shown at the bottom of this table. Both values match the values shown in the trendline equation calculated with the built in functions of MS Excel.

Line	Production units (y)	# of workers (x)	$(y-\mu)^2$	x*y	x^2	y^2
6	61	14	14738	854	196	3721
9	79	14	10692	1106	196	6241
3	95	16	7639	1520	256	9025
7	121	20	3770	2420	400	14641
4	121	21	3770	2541	441	14641
10	163	22	376	3586	484	26569
1	179	24	12	4296	576	32041
8	240	37	3318	8880	1369	57600
5	352	50	28764	17600	2500	123904
2	413	53	53176	21889	2809	170569
number of data points, n	10					
sum	1824	271	126254	64692	9227	458952
mean (μ)	182.4	27.1				
range	352					
Variance (n) (my calcs)			12625			
Stand. Dev. (n) (my calcs)			112			
Variance (Excel)	12625					
Standard dev (Excel)	112					
Sum(x) * Sum(y)	494304					
n * Sum (x*x)	92270					
[Sum (x)]^2	73441					
n * Sum(x) * Sum (y)	646920					
b1	8.11					
b0	-37.3					
n * Sum (y*y)	4589520					
[Sum (y)]^2	3326976					
denominator inside SQRT	2.38E+10					
coefficient of correlation, r	0.9898					
coefficient of determination, r^2	0.9798					

Find the coefficient of determination.
The coefficient of determination is defined as r^2. It is shown at the bottom of the previous table.

Determine the estimated production on a line with 38 workers.
Use the equation found from the linear regression and let x =38. ***$y = (8.11)x - 37.3$***

Therefore the estimated production on a line with 38 workers is 271.

3B: Uncertainty Analysis of Experimental Results

What is Uncertainty Analysis?
All experimental measurements are made with a measuring tool or sensor. These tools have a limit to their accuracy. For example; suppose you wanted to measure the thickness of a sheet of paper using a ruler that has 1/8th inch marks as the smallest measuring increment. When you hold the paper up to the ruler, you could see that the paper is much thinner than 1/8 inch (0.125 inches). You may estimate that the paper is about 1/10 of the smallest increment of measurement of your ruler or 0.0125 inches. However, you really cannot say that this is an accurate measurement. At best, you could say you could measure to half the smallest increment on your ruler, or ± 0.0625 inches. Therefore the best way to report the measured thickness of that sheet of paper is 0.0125 inches ± 0.0625 inches. The "± 0.0625" inches is the uncertainty of your measurement. In this case your uncertainty is huge compared to the actual measured value. You should use a measuring tool with a much smaller resolution in this case. A micrometer that reads values to ± 0.0001 inches would be a much better tool to measure the thickness of a piece of paper since the average thickness of a sheet of copy paper is about 0.004 inches.

Results from some experiments are calculated from several different measured values. The strength of a tensile specimen is equal to the measured "force" at failure divided by the cross-sectional area of the specimen. The cross-sectional area is proportional to the specimen diameter squared. Both the diameter and force measurements will have different uncertainties. ***Uncertainty Analysis*** is the procedure used to determine the propagation of uncertainty when calculating a value like "strength" from multiple measured values.

A method of estimating uncertainty in experimental results has been presented by Kline and McClintock. The method is based on a careful specification of the uncertainties in the various primary experimental measurements. For example, the maximum load-cell reading of the slow-strain-rate (SSR) unit is 7500 lbs ± 0.003 lbs.

When the plus or minus notation is used to designate the uncertainty, the person making this designation is stating the degree of accuracy with which he or she believes the measurement has been made. It is notable that this specification is in itself uncertain because the experiment is naturally uncertain about the accuracy of these measurements.

The uncertainties of the results of the experimental works are calculated by using Kline and McClintock Method. The equation used for this method is given below.

$$W_R = \left[\left(\frac{\partial R}{\partial x_1} w_1\right)^2 + \left(\frac{\partial R}{\partial x_2} w_2\right)^2 + \cdots + \left(\frac{\partial R}{\partial x_n} w_n\right)^2\right]^{\frac{1}{2}} \qquad \text{(Eq. 1)}$$

Where, W_R = the uncertainty in the experimental results

R = the given function of the independent variables $x_1, x_2, \ldots\ldots x_n$

$R = R(x_1, x_2, \ldots\ldots x_n)$

$w_1, w_2, \ldots\ldots w_n$ = the uncertainty in the independent variables

Example: 3B: Uncertainty Calculation in MTS Results

Some of the results generated from a tensile test on the MTS machine are stress (σ), percentage elongation (%El), and percentage reduction in area (%RA). The stress is a function of load (P) and initial cross-sectional area (A_i) of the specimen tested. The %El is a function of change in length (Δl) and original length (l) during the testing, and the %RA is a function of initial cross-sectional area (A_i) and final cross-sectional area (A_f). The P and Δl, l, A_i, and A_f are obtained from the load-cell of the MTS and calipers, respectively. The uncertainty in the load-cell reading on the MTS machine is ± 7 lbs. This is due to electrical noise in the data acquisition system that causes the load reading to fluctuate. The calipers used to measure the length and diameter of the test specimens have an uncertainty of ± 0.001 in.

Calculation of Uncertainty in Stress: *W_σ*

The stress is calculated using the following equation: $\sigma = \dfrac{P}{A} = \dfrac{P}{\frac{\pi}{4}d^2} = \dfrac{4P}{\pi d^2}$

Using Equation 1 to determine the uncertainty in the stress, W_σ

$$W_\sigma = \left[\left(\frac{\partial \sigma}{\partial P} w_P \right)^2 + \left(\frac{\partial \sigma}{\partial d} w_d \right)^2 \right]^{1/2}$$

$$W_\sigma = \left[\left(\left(\frac{4}{\pi d^2} \right) w_P \right)^2 + \left(\left(\frac{-8P}{\pi d^3} \right) w_d \right)^2 \right]^{1/2}$$

Sample Calculation of Uncertainty for Yield Stress:
Measured Values from Experiment:

For yield stress (YS)	σ = 111 ksi
Corresponding average yield load (YL)	P = 5449 lbs
Uncertainty in Load Value	w_P = 7 lbs
Diameter of Specimen	d = 0.25 in
Uncertainty in diameter Value	w_d = 0.001 in

$$W_\sigma = \left[\left(\left(\frac{4}{\pi d^2} \right) w_P \right)^2 + \left(\left(\frac{-8P}{\pi d^3} \right) w_d \right)^2 \right]^{1/2}$$

$$W_\sigma = \left[\left(\left(\frac{4}{\pi (0.25 \text{ in})^2} \right) (7 \text{ lbs}) \right)^2 + \left(\left(\frac{-8(5449 \text{ lbs})}{\pi (0.25 \text{ in})^3} \right) (0.001 \text{ in}) \right)^2 \right]^{1/2}$$

$$W_\sigma = \left[20{,}336 \ \frac{\text{lbs}^2}{\text{in}^4} + 788{,}631 \frac{\text{lbs}^2}{\text{in}^4} \right]^{1/2}$$

$$W_\sigma = 899 \ \frac{\text{lbs}}{\text{in}^2}$$

Therefore the uncertainty in the yield stress calculation due to experimental error is 899 psi. The yield stress can be reported as:

YS = 111 ksi ± 0.899 ksi or YS = 111 ksi ± 0.8%

(since 0.899/111 = 0.008099 or 0.8 %)

Sample Calculation of Uncertainty for Percentage Elongation: $W_{\%EL}$

The % Elongation is determined by measuring the changing length of the specimen after failure and comparing that with the original gage length of the specimen. The equation for percent elongation is:

$$\%\mathrm{El} = \frac{\Delta L}{L} \cdot 100$$

The uncertainty in % Elongation is calculated using Equation 1:

$$W_{(\%EL)} = \left[\left(\frac{\partial(\%EL)}{\partial(\Delta L)} w_{\Delta L} \right)^2 + \left(\frac{\partial(\%EL)}{\partial(L)} w_L \right)^2 \right]^{1/2}$$

$$W_{(\%EL)} = \left[\left(\left(\frac{100}{L} \right) w_{\Delta L} \right)^2 + \left(\left(\frac{-100\Delta L}{L^2} \right) w_L \right)^2 \right]^{1/2}$$

Measured Values from Experiment:

Change in length (ΔL)	ΔL = 0.2107 in
Uncertainty in ΔL Value	$w_{\Delta L}$ = 0.001 in
Gage length (L)	L = 1 in
Uncertainty in L Value	w_L = 0.001 in

$$W_{(\%EL)} = \left[\left(\left(\frac{100}{L} \right) w_{\Delta L} \right)^2 + \left(\left(\frac{-100\Delta L}{L^2} \right) w_L \right)^2 \right]^{1/2}$$

$$W_{(\%EL)} = \left[\left(\left(\frac{100}{1\ \text{in}} \right) (0.001\ \text{in}) \right)^2 + \left(\left(\frac{-100(0.2107\ \text{in})}{(1\ \text{in})^2} \right) (0.001\ \text{in}) \right)^2 \right]^{1/2}$$

$$W_{(\%EL)} = [0.01 + 0.00044]^{1/2}$$

$$W_{(\%EL)} = 0.102$$

Therefore the uncertainty in the % Elongation due to experimental error is 0.102 %. The percent elongation can be reported as:

%El = 21.1 % ± 0.102 %

Homework **Assignment # 1A**

Statistical Analysis

Eight sales people (a population) were monitored in transactions to determine the relationship of dollar sales (y) generated to customer interactions (x) within a set time frame. The experimental values obtained were:

Salesperson	Dollar Sales (y)	Customer Interactions (x)
1	9890	52
2	6774	38
3	10234	49
4	8892	44
5	4312	31
6	15997	56
7	9015	44
8	8320	47

Perform the following (you must show all work):

1. Find the median dollar sales.
2. Find the arithmetic mean of the dollar sales.
3. Find the mode of the customer visits.
4. Find the range of the dollar amount.
5. Find the variance and standard deviation of the dollar amount.
6. Perform a least squares regression of y on x.
7. Plot both the raw data and the linear regression equation on the same graph. Label all axes.
8. Find the coefficient of correlation.
9. Find the coefficient of determination.
10. Determine the estimated dollar sales for 50 customer interactions.
11. Discuss your results.

Assignment # 1B

The resistance of a certain size of copper wire is given as:

$R = R_0[1 + \alpha(T - 20)]$

Where $R_0 = 6 \pm 0.3$ percent is the resistance at 20°C, $\alpha = 0.004°C^{-1} \pm 1$ percent is the temperature coefficient of resistance, and the temperature of the wire is $T = 30 \pm 1°C$. Calculate the resistance of the wire and its uncertainty.

A[*]: Jack P. Holman, "Experimental Methods for Engineers," McGraw-Hill Book Company

Assignment # 1C

Turn in a signed copy of the signature page (found on page 17 of this manual) acknowledging that you have read and understand the safety procedures for this laboratory class.

QUIZ 1

Students should be able to answer questions from any of the material found in Chapter 3 of this manual (pages 18-32). This will be a closed book quiz.

CHAPTER 4

TENSILE TESTING

Chapter 4: Tensile Testing

Objectives:

There are three different objectives to this lab. The first objective is to become familiar with standard procedures for conducting tensile test experiments on metallic materials. The second objective is to learn how to extract important engineering material properties from the data obtained from the tensile test experiment. And the final objective is to become familiar with typical values of engineering properties for common metallic materials such as steel, aluminum, copper, and/or brass.

At the conclusion of this lab, you should be able to:

- Connect strain gages and a clip-on extensometer to a strain indicator box.
- Use the Tinius-Olsen Universal Testing Machine (TOUTM) to test specimens in axial tension.
- Create a stress-strain graph from laboratory data and determine the following properties:
    - Modulus of Elasticity
    - Yield Strength and Yield Strain
    - Ultimate Strength and Ultimate Strain
    - Failure Strength and Failure Strain (% Elongation),
    - % Reduction of Cross-Sectional Area
- Use statistics to obtain mean and standard deviation for these values.
- Use uncertainty analysis to determine measurement error in the calculated values.
- Compare the measured properties from laboratory experiments to expected values obtained from reference sources such as the textbook or internet. A good source of material property data on the internet is: http://www.matweb.com

Description of Experiment

The number of groups and test specimen used in each lab section may vary depending on the size of each class and the time available. Typically, each lab section will be divided into three (3) groups. Each group will be given three (3) specimens of the same material. The specimens will be made from a common engineering metal such as steel or aluminum. You will be told the specific type of material when the specimens are provided to your group. BE CAREFUL when handling these specimens. A strain gage has been bonded to the specimen before the lab and lead wires are soldered to the gage. The lead wires can easily be broken if bumped or dropped. Each specimen will be mounted in the testing machine, connected to the data acquisition box, and tested to failure. Each student will collect all data from the group experiments and write an individual report.

Equipment Needed

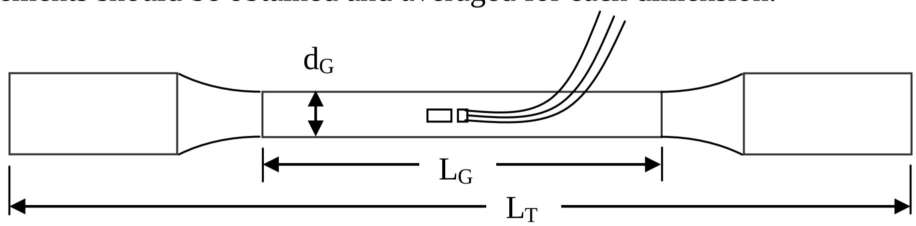
- Metal specimens with attached strain gages (steel, aluminum, brass, copper, …)
- Tinius-Olsen Universal Testing Machine (TOUTM)
- Calipers (for measuring dimensions of the specimens)
- Epsilon Model 3542 clip-on axial extensometers
- VISHAY P3 Data Acquisition Box
- Calculator

Experimental Procedure

Before Testing

- **Specimen Measurements**

Obtain specimens from the laboratory teaching assistant (TA). The specimens should be cylindrical dogbone shaped specimens. Measure the total length, L_T, the gage length, L_G, and the gage section diameter, d_G. The diameter and total length should be easy measurements. The gage length may be difficult because the transition from straight section to curved section may be difficult to find. Make your best measurement and use an appropriate uncertainty value based on your confidence of the measurement. Use calipers provided in the lab for these measurements. Check with the TA about the proper use of the calipers if you need help making the length measurement. A minimum of 3 measurements should be obtained and averaged for each dimension.



Material Type:					
	Measured Dimensions				
	#1	#2	#3	Average	Uncertainty
Specimen #1					
Total Length					
Length of Gage Section					
Diameter of Gage Section					
Specimen #2					
Total Length					
Length of Gage Section					
Diameter of Gage Section					
Specimen #3					
Total Length					
Length of Gage Section					
Diameter of Gage Section					

- **Strain Gage Inspection**

A strain gage should be mounted to each of your three specimens. Visually inspect the strain gage. It should be mounted flush to the specimen with the grid lines in the axial direction of the specimen. Two small lead wires should be soldered from the small pads on the gage to larger pads mounted next to the gage. There are many different types of strain gages but they all work using the same principal. A small voltage is applied to the gage from the data acquisition box. And the gage provides some measurable resistance. The electrical resistance of the gage is proportional to the length of the small wire grid that makes up the gage. As the specimen is strained, the length of the wire grid increases and the resistance changes. The resistance is proportional to the strain in the specimen.

The following strain gage information is needed in order to obtain the proper strain values. Ask the TA for this information if it is not marked on the specimen.

STRAIN GAGE RESISTANCE: ________ (Usually 120 Ohms, but check with TA to be sure.)

GAGE FACTOR: ______________

- **Axial Extensometer**

Beginning in the spring 2010 semester; an axial clip-on extensometer will also be used to measure strain on each specimen.

Manufacturer: Epsilon Technology Corp.
Model: 3542-0200-030-ST
Gage Length: 2 in
Travel: +0.600 in (+30%), -0.200 in (-10%)

- **Strain Gage and Extensometer Balancing**
  - Make sure the strain gage is working while waiting for your turn to test the specimens.
  - Place the specimen flat on a table.
  - Connect the lead wires to the practice strain gage box following the instructions on the inside cover of the box. The TA will be able to assist with this.
  - Make sure the "Amp zero" has been zeroed.
  - Enter the correct gage factor.
  - Set the box to "Run" and try to zero out the strain reading by adjusting the balance dial. Most gages should be able to reach a zero reading when there is no load applied. Occasionally the gage cannot be set to zero but it still may be functioning properly. Make a note of the strain reading prior to testing if the gage will not go all the way to zero. This will be used as a reference value for the strain readings during the test.
  - Disconnect your specimen from the practice box.

- **Measurement Uncertainty**
  - What is the uncertainty in your specimen dimension measurements? ___________
  - What is the uncertainty in the strain readings? ___________
    (Ask the TA or Course Instructor for the strain gage data sheet.)
  - What is the uncertainty in the force readings? ___________
    (Check the load cell information label. Ask the TA or course instructor.)

MODEL 3542 Axial Extensometers

3542 with a 50 mm gage length and ±5% measuring range.

General purpose extensometers for axial tensile, compression and cyclic testing. Gage lengths from 0.5 to 2 inches (and 10 to 50 mm) and measuring ranges from 5% to 100% strain.

These extensometers are designed for testing a wide range of materials, including metals, plastics, composites and ceramics. All will work in both tension and compression. The dual flexure design makes them very rugged and insensitive to vibrations, which permits higher frequency operation.

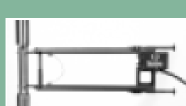
They come standard with Epsilon's quick attach kit, making it easy to mount the extensometer on the test specimen in seconds with one hand. The quick attach kit can be removed, allowing mounting of the extensometer with springs or rubber bands.

The Model 3542 extensometers are strain gaged devices, making them compatible with any electronics designed for strain gaged transducers. Most often they are connected to a test machine controller. The signal conditioning electronics for the extensometer is typically included with the test machine controller or may often be added. In this case the extensometer is shipped with the proper connector and wiring to plug directly into the electronics. For systems lacking the required electronics, Epsilon can provide a variety of solutions, allowing the extensometer output to be connected to data acquisition boards, chart recorders or other equipment. *See the electronics section of this catalog for available signal conditioners and strain meters.*

3542 with a 2" gage length and ±25% measuring range.

3542 axial model used simultaneously with a 3575 transverse model.

3542 with 10 mm gage length and ±10% measuring range.

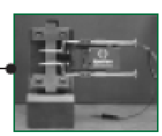


3542 with 2" gage length and +50/-10% measuring range.

3542 with 25 mm gage length and ±10% measuring range.

Extensometers for Composites Compression Testing

Models 3542 and 3442 extensometers can be furnished to clip directly onto composites compression fixtures, such as for ASTM D695. These use specially made quick attach kit wire forms for the customer's fixture. Consult the factory for specifics. *See also the Model 3442 Miniature Extensometer.*



3542 with composites compression fixture for ASTM D695.

Features

- **May be left on through specimen failure.**
- Full bridge, 350 ohm strain gaged design for compatibility with nearly any test system.
- All models can measure in both tension and compression and can be used for cyclic testing.
- Mechanical overtravel stops in both directions.
- All standard units meet existing ASTM class B-1 and ISO 9513, class 0,5 requirements for accuracy.
- Hardened tool steel knife edges are easily replaced. A spare set comes with every extensometer.
- High and low temperature options extend operation from as low as -265 °C (-450 °F) to +175 °C (350 °F).
- Includes high quality foam lined case.
- Replaceable arms and spacers for ease of repair. This also allows changing the gage length for different test requirements.
- Rugged, dual flexure design for strength and improved performance. Much stronger than single flexure designs, this also allows cyclic testing at higher frequencies.
- Standard quick attach kit allows one hand mounting to specimens.

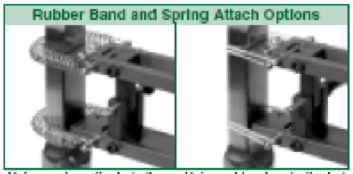
Specifications

Excitation:	5 to 10 VDC recommended, 12 VDC or VAC max.
Output:	2 to 4 mV/V, nominal, depending on model
Linearity:	0.10% to 0.15% of full scale measuring range, depending on model
Temperature Range:	Standard (-ST) is -40 °C to +100 °C (-40 °F to 210°F)
Cable:	Integral, ultra-flexible cable, 8 ft (2.5 m) standard
Standard Quick Attach Kit:	Fits round samples up to 1.0 inch diameter (25 mm) and flats to 0.5 inch thick by 1.25 inch wide (12 mm by 31 mm)
Operating Force:	30 g typical

Options

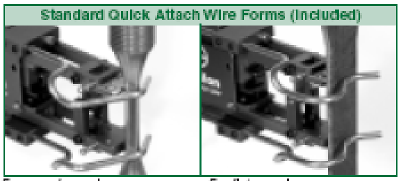
Quick attach kit wire forms for large specimens
Connectors to interface to nearly any brand test equipment
Shunt calibration module (see page 96)
Adapter kits to change gage lengths
Specialty knife edges (see page 97)

Rubber Band and Spring Attach Options



Using springs (included). *Using rubber bands (included).*

Standard Quick Attach Wire Forms (Included)



For round samples. *For flat samples.*

Ordering Information

Model 3542 Available Versions: ANY combination of gage length, measuring range and temperature range listed below is available, except as noted. *Available in intermediate gage lengths on special order.*

Gage Length

U.S.A.	
-0050	0.500"
-0064	0.640"
-0100	1.000"
-0140	1.400"
-0200	2.000"
METRIC	
-010M	10.0 mm
-012M	12.5 mm
-025M	25.0 mm
-050M	50.0 mm

Measuring Range

	% STRAIN	LINEARITY
-005[1]	±5%	
-010	±10%	0.10%
-020	±20%	
-025	±25%	
-050	±50%/-10%	0.15%
-100[2]	+100%/-5%	

Model Number 3542 - __ __ __ __ - __ __ __ - __ __

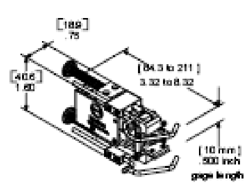
Temperature Range

-LT	-265 °C to 100 °C (-450 °F to 210 °F)
-ST	-40 °C to 100 °C (-40 °F to 210 °F)
-HT1	-40 °C to 150 °C (-40 °F to 300 °F)
-HT2	-40 °C to 175 °C (-40 °F to 350 °F)[3]
-LHT	-265 °C to 175 °C (-450 °F to 350 °F)[3]

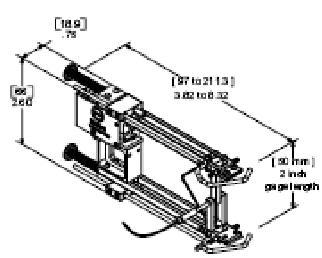
1 *Not available in one-half inch, 10 or 12.5 mm gage lengths.*
2 *For 2 inch and 50 mm gage lengths, linearity is 0.2% typical, (ASTM class B-2).*
3 *Short term use to 200 °C (400 °F) acceptable.*

Example: *3542-0100-020-LT: 1.000 inch gage length, ±20% measuring range, low temperature option (-450 °F to 210 °F)*

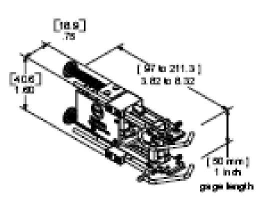
Contact Epsilon for your special testing requirements.



3542 LOW MEASURING RANGE



3542 HIGH MEASURING RANGE



3542 MEDIUM MEASURING RANGE

DIMENSIONS: [mm] inches

Tensile Testing Laboratory Procedure (New Steps added in Spring 2010)

1) Insert Specimen, Connect Strain Gages, and Balance Strain Gages
   a) Place the specimen flat on a table and connect the strain gage lead wires to the Vishay P3 strain gage indicator and recorder attached to the TOUTM.
   b) Read the Vishay P3 operating instructions before the lab. See the file on the course website. The TA's will help with the operation of the P3.
   c) Balance and zero the strain reading on the Vishay P3 indicator/recorder before mounting the specimen in the Tinius Olsen grips.
   d) Balance and zero the force reading on the Vishay P3 indicator/recorder (and on the dial indicator of the Tinius Olsen machine) before mounting the specimen in the Tinius Olsen grips.
   e) Mount the specimen into the grips of the Tinius-Olsen machine.
   f) Note: Mounting the specimen in the grips of the Tinius Olsen may impart a small preload and prestrain on the specimen. This is an actual load and strain on the specimen so do not re-zero the strain or load on the P3 indicator at this point.
2) Mount and Balance the Clip-On Extensometer
   a) Attach the extensometer to the specimen
   b) Connect the lead wires to the Vishay P3 recorder.
   c) Set the extensometer strain value to zero.
   d) Pull the safety pin from the extensometer.
3) Set the Tinius Olsen controls to "lower" and "slower".
4) Set the P3 to record mode.
5) Slowly increase the speed of the crosshead to the desired testing speed. This machine can not be set to a specific testing cross-head velocity. The TA's will help set the speed based on prior experience. The speed will be set so that each specimen will be loaded to failure in approximately 3-5 minutes.
6) The Vishay P3 indicator/recorder will be displaying and recording the force and strain readings at approximately 1 second intervals.
   a) The strain gages will only function up to about 2 % strain (0.02 in/in or 20,000 $\mu\varepsilon$). The failure strain may be much higher than this for some specimens so you may not have enough strain data to construct an entire stress-strain curve.
   b) The extensometer should record strain up to 30%.
7) Stop the test after the specimen fails.
8) Save the data file to the hard drive of the computer in TBE B-150. Use a unique folder/file name to clearly identify this specimen. This may include a series of folders like:
   C:\MEG_302L\F_06\Sect_01\steel_specimen_01.dat
9) Carefully remove the specimen and inspect the shape near the failure surface. Make notes about the appearance of the failure surface. Take a picture and include it in the report if a digital camera is available. If you take a picture or pictures; make sure you can match the picture to a specific specimen and data file later on when you are working on your report.
10) Carefully put the two pieces of the specimen together and measure the final length of the specimen. Use this length to determine the failure strain of the specimen.
11) Measure the diameter of the specimen at the failure location. Use this measurement to determine the % reduction in cross-sectional area.
12) Repeat the experiment with the next specimen. Your group should be testing three specimens of the same material. The material type is identified by colored markings on the ends of the specimen.

Data reduction procedures to include in your report

- Description of specimens including dimensions, materials, and preparation procedures.
- Description of equipment and testing procedures.
- Description of data reduction methods. The data file should have 3 columns of data for each specimen: force, strain from the strain gage, and strain from the extensometer. Create separate stress-strain curves from the strain gage and extensometer data. If the experiment runs smoothly, these curves should match well for low strains but you may only get extensometer data at the higher strains. You must determine the following calculations for at least 3 specimens of the same material:

    1. Copy the raw data from the computer, which should have 4 columns (time, force, and strain gage strain, and extensometer strain). Make sure you know the units used in the data file before you leave the lab.
    2. Add another column for stress and calculate the engineering stress ($\sigma = P/A_0$) for each force reading. A_0 is the original cross-sectional area of the gage section of the specimen.
    3. Create a graph of stress vs. strain from the strain gage data and another one from the extensometer data. Clearly label the title identifying the material and specimen number. Clearly label the axes with the correct units. Remember that the strain gage will probably stop working at some time during the test. The indicator may show a very high constant value at some point after the gage fails. Do not include these values in the graph.
    4. Determine the Modulus of Elasticity by measuring the slope of the initial linear portion of the stress-strain curve (from strain gage and extensometer).
        - MS Excel can do this by displaying the equation of a line fit through a portion of the stress-strain curve.
        - NOTE: The curve may have an initial non-linear portion that is due to the slipping and tightening of the grips as the specimen is initially loaded. Ignore this part of the curve when determining the Modulus of Elasticity.
        - If using MS Excel, you may need to create a full stress strain graph with all the data. Make a copy of this graph and then delete the initial data points that are outside the linear region. Also delete any data points near the end of the file if they are outside the linear region. Then use the curve fitting tool to find the equation of the line and determine its slope.
    5. Determine the Yield point (Yield Stress and Yield Strain) in the curve using the 0.2% offset method discussed in class and in the textbook. You may need to make another graph with a close-up view of the initial portion of the data.

6. Determine the Ultimate stress in the material. This will correspond to the stress when the loading force has its highest value.
7. Determine the failure stress by looking at the stress reading just before the specimen broke.
8. Determine the failure strain by measuring the final length of the specimen. The failure strain (or % elongation) is equal to the overall change in length of the specimen divided by the original gage length. This assumes that all permanent deformation occurs in the gage length.
9. Determine the % reduction in area by measuring the final diameter of the specimen at the failure surface.
10. Calculate the mean, range and standard deviation for the modulus of elasticity, yield stress, yield strain, ultimate stress, failure stress, failure strain, and % reduction in area for the 3 specimens of the same material that your group tested.
11. Determine the uncertainty in your calculations based on measurement errors.
12. Compare your results to expected values form manufacturer’s data or reference sources.
13. Discuss your results, including some discussion on the importance of using a statistical and uncertainty analyses to determine material properties from lab data, as opposed to simply calculating the mean of the lab data.

Submit this report as Lab #1 one week after completing the lab experiment.

ME 302L / CEE 370L: Tips for the Tensile Testing Lab

Data Reduction Requirements:

- □ Plot Stress vs. Strain graph for all 3 of your group's specimens
  - Show linear regression of elastic portion (for your determination of E) and 0.2% offset line
- □ Determine the following (for each specimen) from your graph/data and tabulate:
  - E (modulus of elasticity)
  - 0.2% offset yield stress
  - 0.2% offset yield strain
  - ultimate stress
  - fracture stress
  - average % elongation (a.k.a. fracture strain)
  - % reduction in area
- □ Calculate mean, range and standard deviation for the calculations for E, yield stress, yield strain, ultimate stress, fracture/failure stress, fracture strain, % reduction in area
- □ Determine uncertainty for stress and modulus of elasticity
- □ Look up the material properties in your textbook, and compare with your measured values (do % error, and perhaps make a table for comparison)

How to do 0.2% offset:

Follow these instructions once you have calculated and plotted stress and strain.

1) Determine your "good" data set – Remove all "bad" strain data points from your graph.
2) Determine which point delineates the end of the linear elastic section of the graph
3) Divide data set into 2 series: linear and non-linear
4) Do Excel regression line (set the intercept = 0) of linear portion to determine E (slope of line)
5) Use point-slope to determine your 0.2% offset equation, $y-y_1 = E*(x-x_1)$, where $x_1=0.002$, and $y_1=0$
6) Choose one other y-coordinate that will intersect your stress-strain graph
7) With those 2 points you can graph the line in Excel.
8) Where the line intersects the stress-strain graph is the 0.2% offset yield stress and strain.

DON'T FORGET TO FORMAT! Your lab must have all these sections:

- □ Title Page
- □ Table of Contents
- □ Table of Graphs and Figures (necessary if the report has more than 5 graphs and tables)
- □ Abstract (state objectives *and* summary of results)
- □ Introduction (give background information and applications)
- □ Experimental Procedure (don't copy the lab manual)
- □ Results (identify equations, tabulate results if necessary, number figures & tables)
- □ Analysis (do % error, uncertainty, statistical analysis, and talk about results)
- □ Conclusion (what does it all mean? Did you do what you set out to accomplish?)
- □ *Optional:* Appendices (if references were used and to present raw data)

QUIZ 2

Students should be able to answer questions from any of the material found in Chapter 4 of this manual. In addition, students should know the properties (SI and US systems of units) of some of the most common engineering materials such as:

Material	Specific Weight or Density lbf/in^3 [kg/m^3]	Ultimate Tensile Strength ksi [MPa]	Tensile Yield Strength ksi [MPa]	Modulus of Elasticity Msi [GPa]	Ductility (% Elongation)
Structural Steel (ASTM-A36)	0.284 [7860]	58 [400]	36 [250]	29 [200]	21
Stainless Steel (AISI 302 Cold Rolled)	0.286 [7920]	125 [860]	75 [520]	28 [190]	12
Aluminum Alloy 6061-T6	0.098 [2710]	38 [260]	35 [240]	10.1 [70]	17
Nylon 6/6 Molding Compound	0.0412 [1140]	11 [75]	6.5 [45]	0.4 [2.8]	50

Beer, Johnston, DeWolf, "Mechanics of Materials" 3rd Edition, McGraw Hill, 2001, pp 746-749.

CHAPTER 5

POISSON'S RATIO

Chapter # 5: Poisson's Ratio

This lab will consist of experimentally determining the value of Poisson's Ratio for three different materials (steel, copper, and aluminum) by performing a bending experiment on a flat bar and measuring the axial and transverse strain.

At the conclusion of this lab, you should:

- Know the definition of Poisson's Ratio and expected values for Poisson's Ratio.
- Be able to determine Poisson's Ratio from lab data.

Prior to reporting to the lab, prepare for this lab by obtaining "published" values of Poisson's Ratio for steel, copper, and aluminum.

Note: Your text does not give an actual published value for Poisson's Ratio. However, your text gives the following equation from which you can determine a "published" value:

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

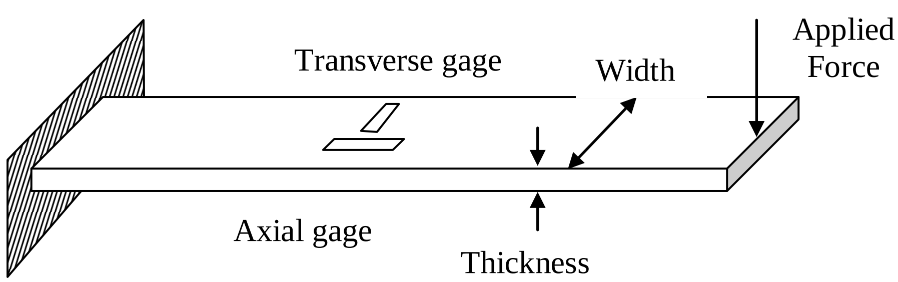
where G is the Modulus of Rigidity, E is the Modulus of Elasticity, and ν is Poisson's ratio. G and E can be found in the appendix of your text. Just plug into the above equation and solve for ν.

Background

The Poisson's Ratio is a material property that describes the relative amount of transverse deformation that will occur in a specimen when it is loaded in the axial direction. Poisson's Ratio, ν, is defined as:

$$\nu = -\frac{\varepsilon_{Transverse}}{\varepsilon_{Axial}}$$

This experiment uses a bending specimen to create axial and transverse strains in a specimen. It is not necessary to fully understand bending stresses and strains in order to conduct this experiment. It is important to realize that the applied force in the bending test configuration shown below causes stress in the specimen in the axial direction. Therefore, there will be an axial strain due to the applied load. There will also be a transverse strain due solely to the Poisson's Ratio effect in the material since there is no load in the transverse direction of the specimen.



Description of Poisson's Ratio Experiment

Equipment Needed

- Three metal specimens (steel, copper, aluminum) with attached strain gages
- Strain Indicator Box (2 channels)
- Micrometer

Procedure

For each of the specimens:

- Measure the width and thickness of the specimen.
- Attach the strain gages to the indicator boxes, and determine which box is measuring axial strain and which is measuring transverse strain.
- Clamp the specimen to the table, with most of the specimen hanging over the edge of the table. Make sure the strain gages are not close to the table edge.
- Mark a point on the specimen at which to hang the weights. Place the weight hanger on the specimen, and record the strain data.
- Load the weights. After hanging each weight, record the strain data. Continue until all weights have been placed on the weight hanger.
- Repeat the procedure for each specimen.

Data Reduction

Your lab report must include at least the following:

- The test setup and detailed procedures.
- Calculate the value of Poisson's Ratio at each increment, then average to obtain ν.
- Compare the calculated value of ν to the published values for each of the materials.
- Make a plot of the data with ε_x on the *x*-axis and $-\varepsilon_y$ on the *y*-axis.
- Perform a linear regression and obtain the slope of the line, which should then be compared to the value of ν calculated above.
- Include all other data, equations, calculations, and discussion you believe is necessary to demonstrate that you have achieved the objectives of this lab.

Submit this report as Lab #2 one week after completing the lab experiment.

Tables on the following page can be used to record data during experiments.

Data for Steel Specimen

Load (g)	$\varepsilon_{transverse}$ ($\mu\varepsilon$)	ε_{axial} ($\mu\varepsilon$)	ν: Poisson's Ratio

Data for Aluminum Specimen

Load (g)	$\varepsilon_{transverse}$ ($\mu\varepsilon$)	ε_{axial} ($\mu\varepsilon$)	ν: Poisson's Ratio

Data for Copper Specimen

Load (g)	$\varepsilon_{transverse}$ ($\mu\varepsilon$)	ε_{axial} ($\mu\varepsilon$)	ν: Poisson's Ratio

CHAPTER 6

TORSION

Chapter # 5 Torsion of Circular Sections

The objective of this lab is to experimentally explore the relationships between several different variables in an experiment that applies torsional load to a circular cross-section rod of length L. Variables that will be investigated include the applied torque, angular deflection, length of rod, polar moment of inertia, and shear modulus. The TQ Products STR6 experimental apparatus is used for this experiment. See the following pages for a complete description of the experiments to be performed as part of this lab.

The experiments described on the following pages mention the use of steel and brass specimens. The experiments usually work better with the brass specimens. The teaching assistant for your section may opt to use only the brass specimens and test a wider range of specimen lengths. If you use the steel specimens and the results do not come out as expected; think about and discuss possible causes. Steel has a higher shear modulus than brass. Is the specimen slipping in the grips? Could the specimen have been overloaded beyond its yield point?

SECTION 1 INTRODUCTION AND DESCRIPTION

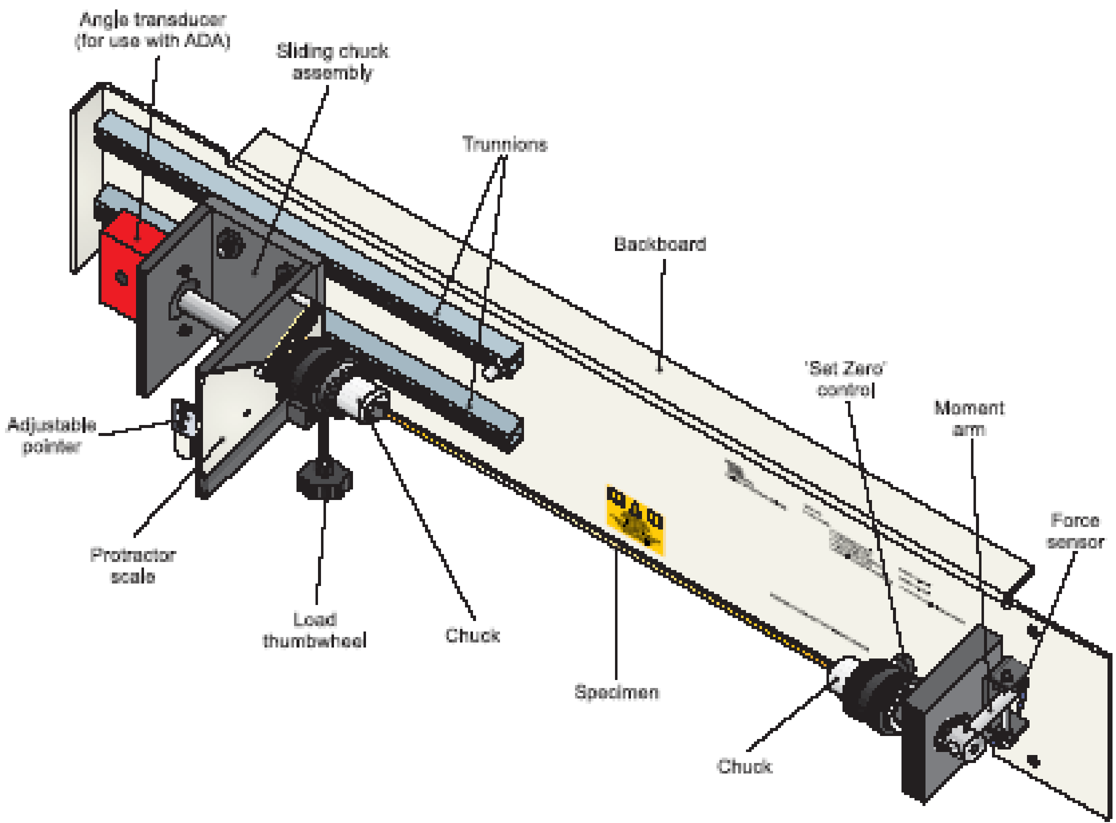


Figure 1 Torsion of circular sections experiment

Introduction

This guide describes how to set up and perform experiments on the torsion of circular sections. It clearly demonstrates the principles involved and gives practical support to your studies.

Description

Figure 1 shows the Torsion of Circular Sections experiment. It consists of a backboard with chucks for gripping the test specimen at each end. The right-hand chuck connects to a load cell using an arm to measure torque. A protractor scale on the left-hand chuck measures rotation. A thumbwheel on the protractor scale twists specimens. Sliding the chuck along the backboard alters the test specimen length.

The backboard has some formulae and data printed on it. Note this information – it will be useful later.

How to Set up the Equipment

The Torsion of Circular Sections experiment fits into a Test Frame. Figure 2 shows the Torsion of circular sections experiment assembled in the Frame.

Before setting up and using the equipment, always:

- Visually inspect all parts, including electrical leads, for damage or wear.
- Check electrical connections are correct and secure.
- Check all components are secured correctly and fastenings are sufficiently tight.
- Position the Test Frame safely. Make sure it is on a solid level surface, is steady and easily accessible.

Never apply excessive loads to any part of the equipment.

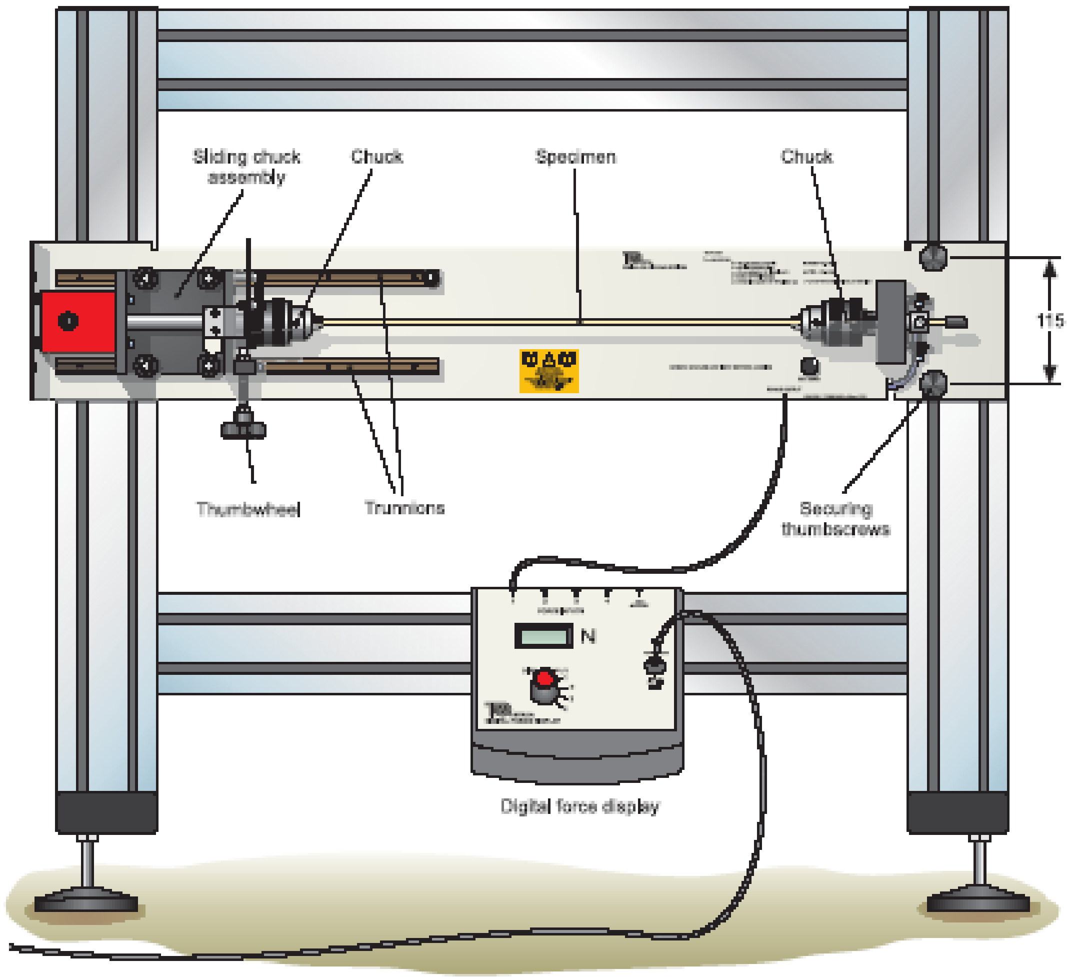


Figure 2 Torsion of circular sections in the structures frame

Steps 1 to 3 of the following instructions may already have been completed for you.

1. Place an assembled Test Frame (refer to the separate instructions supplied with the Test Frame if necessary) on a workbench. Make sure the 'window' of the Test Frame is easily accessible.
2. There are two securing nuts in each of the side members of the frame (on the inner track). Move one to the outer track (see STR1 instruction sheet) then slide them to approximately the positions shown by the thumbscrews in Figure 2.
3. Lift the backboard into position and have an assistant secure the backboard with thumbscrews into the securing nuts. If necessary, level the backboard by loosening the thumbscrews on one side and tightening when ready.
4. Make sure the Digital Force Display is 'on'. Connect the mini DIN lead from 'Force Input 1' on the Digital Force Display to the socket marked 'Force Output' on to the right underside of the backboard.
5. Carefully zero the force meter using the dial. Gently apply a small torque to the left-hand chuck and release. If necessary, zero the meter again.

SECTION 2 EXPERIMENTS

Experiment 1: Torsional Deflection of a Solid Rod

This experiment examines the relationship between torque and angular deflection of a solid circular section. Further work will show how the properties of the material affect this relationship.

With a pencil and a rule, mark the steel and brass rods with these distances from the left-hand end (note that the rubber tip is on the right-hand end):

- 15 mm,
- 315 mm,
- 365 mm,
- 415 mm,
- 465 mm,
- 515 mm.

Wind the thumbwheel down to its stop. Position the steel rod from the right-hand side with the rubber tipped end sticking out. Line up the first mark with the left-hand chuck (note the jaws of the chuck move outward as they close!). Tighten it fully using the chuck key in the three holes.

Undo the four thumbnuts which stop the chuck from sliding. Slide the chuck until the last mark (515 mm) lines up with the right-hand chuck. This procedure sets the rod length at 500 mm. Fully tighten the right-hand chuck using the chuck key in each of the three holes.

Wind the thumbwheel until the force meter reads 0.3 N to 0.5 N. Zero the force meter and the angle scale using the moveable pointer arm. Wind the thumbwheel so the force meter reads 5 N and then back to zero. If the angle reading is not zero check the tightness of the chucks and start again.

Take readings of the angle every 1 N of force: you should take the reading just as the reading changes. Take readings to a maximum of 5 N of force. Enter all the readings into Table 2. To convert the load cell readings to torque multiply by the torque arm length (0.05 m).

Repeat the set up and procedure for the brass rod and enter your results in Table 3.

Force (N)	Torque, T (Nm)	Angular deflection (°)
0	0	0
1		
2		
3		
4		
5		

Table 2 Results for steel rod

Force (N)	Torque, T (Nm)	Angular deflection (°)
0	0	0
1		
2		
3		
4		
5		

Table 3 Results for a brass rod

From your results, on the same graph plot torque versus angle for both rods

Comment on the shape of the graph. What does it tell us about how angle of deflection varies because of an increased torque? Name at least three applications or situations where torsional deflection would undesirable and one application where it could be desirable or of use.

Take a look at the formulas on the backboard that predicts the behaviour of the rods. What would happen to the relative stiffness of the rod if the diameter were increased from 3 mm to 4 mm?

Further Work

Measure the diameter of both the rods with the vernier as accurately as you can (remember the affect of a small error in the diameter!). Calculate J values for each rod using the formulae on the backboard of the equipment.

Fill in Tables 4 and 5 from your experimental results to establish values of TL and $J\theta$. Remember you must convert your angle measurements from degrees to radians (2π radians = 360°).

Diameter of steel section, d	_________ mm
Polar moment of inertia, J	_________ $\times 10^{-12}$ m^4
Length L	0.5 m

Torque (Nm)	**Angular deflection, θ (rad)**	TL	$J\theta \times 10^{-12}$
0			
0.05			
0.10			
0.15			
0.20			
0.25			

Table 4 Calculated values for a steel rod

Diameter of brass section, d	_________ mm
Polar moment of inertia, J	_________ $\times 10^{-12}$ m^4
Length L	0.5 m

Torque (Nm)	**Angular deflection, θ (rad)**	TL	$J\theta \times 10^{-12}$
0			
0.05			
0.10			
0.15			
0.20			
0.25			

Table 5 Calculated values for a brass rod

Plot a graph of TL against $J\theta$. Examine the torsion formula and say what the value of the gradient represents. Does the value compare favourably with typical ones?

Experiment 2: The Effect of Rod Length on Torsional Deflection

This experiment examines the relationship between torsional deflection and rod length at a constant torque.

If you have completed Experiment 1 you will have already completed some of the following steps. In which case you can leave the brass rod in place at 500 mm long.

With a pencil and a rule, mark the steel and brass rods these distances from the left-hand end (note that the rubber tip is on the right-hand end):

- 15 mm,
- 315 mm,
- 365 mm,
- 415 mm,
- 465 mm,
- 515 mm.

Wind the thumbwheel down to its stop. Position the steel rod from the right-hand side with the rubber tipped end sticking out. Line up the first mark with the left-hand chuck (note the jaws of the chuck move outward as they close!). Tighten it fully using the chuck key in each of the three holes.

Undo the four thumbnuts which stop the chuck from sliding. Slide the chuck until the last mark (515 mm) lines up with the right-hand chuck. This procedure sets the rod length at 500 mm. Fully tighten the right-hand chuck using the chuck key in each of the three holes.

Wind the thumbwheel until the force meter reads 0.3 N to 0.5 N. Zero the force meter and the angle scale using the moveable pointer arm. Wind the thumbwheel so the force meter reads 5 N and then back to zero. If the angle reading is not zero check the tightness of the chucks and start again.

Wind the thumbwheel so the torque is 0.15 Nm (a reading of 3 N) and note down the angle in Table 6. Reduce the length of the rod to the next mark (450 mm) and reset. Take a reading of angle at the same torque and record. Repeat this procedure for lengths down to 300 mm.

Dia. of brass rod	_____ mm	Torque, *T*	0.15 Nm

Length (m)	Angular deflection (°)
0.30	
0.35	
0.40	
0.45	
0.50	

Table 6 Results for a brass rod

Plot a graph of angular deflection against rod length. Comment on the shape of the plot.

On most front-wheel drive vehicles have unequal length drive shafts (from side-to-side). This is because of the gearbox position being at one end of the engine. This mismatch in length causes an undesirable effect on the steering as the car accelerates (that is, as torque from the engine increases). Why is that? What could eliminate the effect?

Experiment 3: Comparison of Solid Rod and Tube

This experiment compares the torsional deflection of a solid rod and a tube with a similar diameters.

With a pencil and a rule mark the brass tube and brass rods at 15 mm and 515 mm from the left-hand end (the end without the rubber tip).

Wind the angle thumbwheel down to its stop. Position the brass tube in from the right-hand side with the rubber tip end sticking out. Line up the first mark with the left-hand chuck (note the jaws of the chuck move outward as they close!). Tighten it fully using the chuck key in each of the three holes.

Undo the four thumbnuts that stop the chuck from sliding. Slide the chuck until the last mark (515 mm) lines up with the right-hand chuck. This sets the rod length at 500 mm. Fully tighten the right-hand chuck using the chuck key in each of the three holes.

Wind the thumbwheel until the force meter reads 0.3 N to 0.5 N. Zero the force meter and the angle scale with the moveable pointer arm. Wind the thumbwheel so the force meter reads 5 N and then back to zero. If the angle reading is not zero check the tightness of the chucks and start again.

Take readings of the angle every 1 N of force: you should take the reading just as the reading changes. Take readings to a maximum of 5 N of force. Enter all the readings into Table 7. To convert the load cell readings to torque multiply by the torque arm length (0.05 m).

If you have completed Experiment 1, enter your results for the solid brass rod in Table 7. If not, repeat the set up and procedure for the solid brass rod.

Force (N)	Torque (Nm)	Rod angular deflection (°)	Tube angular deflection (°)
0			
1			
2			
3			
4			
5			

Table 7 Results for brass rod and tube

Calculate the J values for the solid rod and tube. To calculate J for a tube, find J for a solid of the same diameter then subtract J for the missing material in the centre. Examine your results and the J values you have calculated and comment on the effect of the missing material.

Assuming a density of 8450 kgm^{-3} for brass, work out the nominal mass per unit length of both the tube and the solid rod. Comment on the efficiency of designing torsional members out of tube instead of solid material.

QUIZ 3

Students should be able to answer questions from any of the material found in Chapter 5 & 6 of this manual.

CHAPTER 7

BENDING

AND THE

MODULUS
OF
ELASTICITY

Chapter # 7 Bending and the Modulus of Elasticity

This lab will use the bending equations to find the Modulus of Elasticity of a specimen. At the conclusion of this lab, you should:

- Be familiar with the equation for bending stress.
- Be able to calculate the bending stress at any point along a beam.
- Use laboratory results to construct a stress-strain graph of a beam in bending.
- Find the Modulus of Elasticity from lab data collected from a cantilever beam in bending.

To prepare for this lab, look up the equation for calculating bending stress. Next, assume the following:

$h = 0.258$ inches

$b = 1.00$ inches

$L = 4.40$ inches

$M = 1916$ grams

$\varepsilon_x = 0.000112$

where h is the bar thickness, b is the bar width, L is the distance from the application of the force to the strain gage, M is the mass in grams, and ε_x is the strain recorded from the strain box. Using the data provided, calculate the stress at the strain gage, then calculate the Modulus of Elasticity for this single data point using Hooke's Law.

(hint: units, units, units, units, units)

Description of Experiment

Modulus of Elasticity

Equipment Needed

- Three metal specimens (steel, copper, aluminum) with strain gages attached
- Strain Indicator Box
- Micrometer
- Ruler

Procedure

For each of the specimens, perform the following:

- Measure and record the width and thickness of the specimen.
- Attach the strain gage leads to the strain indicator box. Zero the box.
- Clamp the specimen to the edge of the table with the axial strain gage facing up. Make sure the strain gage is not near any support.
- Place the mass hanger near the end of the specimen.
- Measure and record the distance from the mass hanger to the strain gage.
- Record the strain reading resulting from the mass hanger.
- One at a time, place each of the 500-g masses in the mass hanger. After each mass is added, record the resulting strain reading.
- Repeat for all specimens.

Elements to include in your report

Your lab report must include at least the following:

- Calculate stress for each load reading for each specimen.
- Calculate E using Hooke's Law for each load reading for each specimen.
- Plot stress versus strain for each specimen.
- Calculate E using linear regression for each specimen. Set the y-intercept to zero for the linear regression.
- For each specimen, compare the results to each other and to the published values of E. Calculate percent error and cite source of published value.
- Include all other data, equations, calculations, and discussion you believe is necessary to demonstrate that you have achieved the objectives of this lab.

Data for Steel Specimen

Load (g)	$\varepsilon_{transverse}$ ($\mu\varepsilon$)	ε_{axial} ($\mu\varepsilon$)	ν: Poisson's Ratio

Data for Aluminum Specimen

Load (g)	$\varepsilon_{transverse}$ ($\mu\varepsilon$)	ε_{axial} ($\mu\varepsilon$)	ν: Poisson's Ratio

Data for Copper Specimen

Load (g)	$\varepsilon_{transverse}$ ($\mu\varepsilon$)	ε_{axial} ($\mu\varepsilon$)	ν: Poisson's Ratio

CHAPTER 8

APPLICATION

OF

STRAIN GAGES

TO

TENSILE SPECIMENS

Chapter 8: Specimen Preparation for Tensile Testing (Application of Strain Gages)

Objectives

The primary objective of this lab is to learn the proper procedure for bonding and soldering a strain gage to a test specimen. Each student will bond and solder a practice gage to a scrap piece of metal. Then each student will bond and solder a strain gage to a specimen that will be used for the Tensile Testing Lab next semester.

Procedures

PreLab

Students are responsible for reading the "Student Strain Gage Manual" prior to Lab #2. The manual can be downloaded from the course website. Hardcopies of this manual will be available for use in the laboratory but can not be taken from the lab.

Lab

All students will view a 15 minute video that describes the strain gage application procedure. All students will follow the strain gage application procedures described in this section. The procedures were taken from the "Introduction to Strain Gage Technology" manual provided by the Vishay Measurements Group.

Assignment

Part A (50 %): Each student will submit a tensile specimen with a working strain gage to the laboratory teaching assistant. You will be graded on the functionality of your gaged specimen. Does it work? Can the gage be balanced? Does it look neat? Do the solder connections look secure?

Applying gages takes a combination of skill and art that becomes much easier with experience. It is rare to get a gage working the first time you try. We have allotted 2 weeks for this exercise so you have time to try more than once.

Part B (50 %): Submit a brief summary of your experience (2 pages maximum) including materials used, Specimen preparation procedure, Gage Mounting procedure, Soldering Procedure, Gage Testing Procedure. Answer the following questions in this report:

1) What is purpose of the many specimen preparation procedures?
2) Briefly summarize how to test if your gage is working properly.
3) What experiments besides tensile testing could benefit from a properly installed strain gage?
4) What was the most difficult step in applying a strain gage and why?

Equipment Needed

The following equipment and supplies are needed for this lab:

- Strain gage supply cart from the machine shop
    - Strain gages
    - Bonding supplies
    - Soldering supplies
- Soldering Irons from the ME 302 Supply cabinet
- Tensile test specimens
    - Variety of specimens stored in the machine shop
- Portable Strain Gage Reader (Vishay P3 or equivalent)

On-Line Manuals

The Vishay student strain gage manual and the P3 user manual can be downloaded from the course website located at the following site:

http://www.me.unlv.edu/~bj/MEG_302L_web/SYLLABUS.html

A large amount of information regarding strain gages can be found directly from the Vishay website:

www.vishay.com

The strain gage techniques section of the Vishay website can be found here:

Strain Gage Installation Information

Hardcopy booklets of the strain gage manual are available in the lab for use in the lab.

We have booklets in the lab that provide details of the strain gage installation process.

We also have a video describing the process.

QUIZ 4

Students should be able to answer questions from any of the material found in Chapter 8 of this manual and the handouts used in class.

CHAPTER 9

DEFLECTION

OF

BEAMS

Chapter 9: Deflection of Beams

This lab will involve loading specimens in bending to obtain deflection and strain data. Two 12-in specimens will be loaded within the elastic region of the material. Strain data and deflection data will be obtained, and compared to the experimental deflection and stress obtained from calculations.

At the conclusion of this lab, you should:

- Be familiar with the equation for bending stress.
- Be able to calculate bending stress at any point along a beam.
- Be able to derive the deflection equation for a beam in 3-point bending.
- Be able to calculate the deflection at any point along a beam in 3-point bending.
- Be able to compare theoretical deflection to actual measured deflections.

Prior to reporting to the lab, prepare for the lab by completing the following exercise:

A 12-in long rectangular beam is simply supported. The beam is made of 6061 Aluminum, with outside dimensions of 1.00 in. x 1.00 in. and inside dimensions of 0.760 in. x 0.760 in. A load of 100 lb_f is applied to the center of the beam. The measured deflection at the center of the beam is 0.007 in., and a strain gage located at $x = 3.25$ in. records a strain of 137 $\mu\varepsilon$ (137 x 10^{-6} or 0.000137). Given the expression for the centerline deflection,

$$\delta_{\frac{L}{2}} = \frac{-wL^3}{48EI}$$

Calculate the theoretical deflection at the centerline and compare to the recorded value. Calculate the percent difference. Using the bending equation, calculate the theoretical stress at $x = 3.25$ in. Convert the recorded strain to a stress using Hooke's Law and compare to the theoretical stress. Calculate the percent difference.

Description of Experiment

Deflection of Beams

Equipment Needed

Aluminum specimens with strain gages

Tinius-Olsen Universal Testing Machine

Strain Indicator Box (2)

Calculator

Procedure

For each of the specimens:

- Measure the thickness, width, length, and wall thickness (as applicable) of the specimen.
- Measure the distance from the support to the strain gages.
- Mount the specimen in the Tinius-Olsen Universal Testing Machine (TOUTM). Center the specimen, and lower the cross-head until the cross-head is close to the specimen.
- Place the ball-bearing on the centerline of the specimen. Lower the cross-head until it just contacts the ball bearing, then raise the cross-head slightly until no load is shown.
- Set the dial indicator to the cross-head, and zero the dial indicator.
- Connect both strain gages to strain indicator boxes.
- Slowly load the specimen, recording strain and deflection data at 25-lb increments. Continue to increase the load until you have enough data points (approximately 10) to make a good graph of load versus deflection. **DO NOT EXCEED about 500 lb**.
- Repeat the procedures for the other specimen.

Elements to include in your report

Your lab report must include at least the following:

- Calculate the stress at the strain gages and compare the stress obtained using the strain gage data. Plot theoretical and experimental stress vs. load on the same graph.
- Calculate the deflection at the centerline of the specimen, and compare to the recorded deflection data.
- Determine the percentage difference for each load interval.
- For each specimen, plot load versus theoretical deflection and load versus actual deflection on the same graph.
- Include all other data, equations, calculations, and discussion you believe is necessary to demonstrate that you have achieved the objectives of this lab.
- In some lab sections, the experimental and theoretical strain values are reasonably close but the experimental and theoretical deflections have huge discrepancies. Provide reasons for this large error if it occurs.

Reading #	**Force (lb)**	**Deflection (in)**	
		T-Beam	**Box Beam**
1	0	0	0

CHAPTER 10

COLUMN BUCKLING

Lab # 9
Column Deflection and Critical Buckling Loads

Objectives

1. Establish a linear relationship between the buckling load (P_{cr}) and the length of the strut for different end conditions.
2. Compare the experimental P_{cr} with the theoretical one.

When a column is loaded in axial compression, the system will remain stable as long as the applied load is smaller than the Euler buckling or critical load, P_{cr}. A stable system is a system that returns to equilibrium when the load is removed.

As the applied load exceeds P_{cr}, the system becomes unstable, resulting in column bending and ultimate failure. The value of P_{cr} varies with the end conditions for the column. The following relationships have been established for common end conditions:

$$P_{cr} = \frac{n^2 \pi^2 EI}{L^2} \qquad n = 1, 2, 3, \ldots$$

The value of n is determined by the boundary conditions:
For a pinned-pinned condition, n = 1.
For a pinned-fixed condition, n = 1.414.
For a fixed-fixed condition, n = 2.

Description of Experiment for Column Deflection and Critical Loads

Equipment needed:

Strut Machine
Aluminum Specimens of Different Lengths
Yardstick or Tape Measure
Calculator

Procedure

- Prior to starting the experiment, measure the aluminum specimens of different lengths.
- Assuming that E = 69 GPa for aluminum, calculate the values of the critical load, P_{cr}, for pinned-pinned, pinned-fixed, and fixed-fixed end conditions for the five specimens of different lengths.
- Place the column in the strut machine.
- Apply load slowly until the specimen buckles.
- Record the buckling load for each specimen and end condition.

Elements to include in your Report

Your laboratory report must include the following:

- Calculations for determining the critical load (P_{cr}) of each specimen for each end condition.
- Plot a graph of P_{cr} versus $1/L^2$ for the three end conditions for five different lengths on the same graph.

E (N/m^2) =		
I (m^4) =		
Pinned-Pinned	**Pinned-Fixed**	**Fixed-Fixed**
L = m	L = m	L = m
n =	n =	n =
P_{cr} = N	P_{cr} = N	P_{cr} = N
$P_{cr,actual}$ = N	$P_{cr,actual}$ = N	$P_{cr,actual}$ = N

Further Calculations of Critical Buckling Load				
Length (m)	**$1/L^2$ (m^{-2})**	**Pinned-Pinned**	**Pinned-Fixed**	**Fixed-Fixed**
0.28				
0.30				
0.32				
0.34				
0.36				