ASEN 3112 STRUCTURES

Lab 1 DESCRIPTION

Spring 2020

Version: January 27, 2020

I Summary

The first experimental lab involves testing two circular *thin wall* sections, one closed and one open, under applied torque, using an MTS Torsional Testing Machine. The learning objectives of this lab are to:

- **Understand** the factors that must be considered when choosing the machine, sensors, and experimental setup for a materials test.
- **Contrast** shear stress and strain plots derived from extensometer measurements and from the MTS Torsional Testing Machine measurements.
- **Research** an alternate sensor for calculating shear stress and **contrast** this sensor with the extensometer used in the lab.
- **Calculate** the torsional rigidity and this measurement's uncertainty for a shaft given messy experimental data.
- **Compare** experimental results and theoretical calculations in order to **evaluate** the accuracy of the assumptions underlying the theory used.

II Timetable, groups, and logistics

II.1 Timetable

The experimental procedure will be described in demos that will be held in the Material Testing room off of PILOT (AERO 141C), during the Recitation times. Attendance is mandatory and will be taken at the start of each demo; failure to attend will result in deduction of 50% of the grade. Lab groups and demo times were decided in recitation, and have been posted to Canvas. Students must attend the laboratory demonstration during their group's assigned time. Attendance at a different demo requires prior written approval from the instructors and will only be granted on account of a bona-fide reason, such as a medical emergency or an academic-related activity. In case of an emergency or unavoidable absence, students should contact the instructors as soon as possible.

II.2 Lab Groups

Lab groups have been chosen and are posted to Canvas. Each group selects a leader (the Group Leader, or GL) who will have the following responsibilities:

- Divide tasks to be accomplished in writing the report (e.g. writing specific sections, analyzing data and producing necessary plots/figures).
- Compile and edit the final report (ensure consistency between sections and make sure that other member's contributions are satisfactory).
- Provide internal deadlines to group members so that the lab report project stays on schedule.
- Keep a record of delegated tasks, internal deadlines, and confirmations from team members. This record can simply be a thread of emails between the group leader and group members. This will not be turned in but will be used by the TAs to resolve any disputes about participation scores.
- Provide a participation report for your group with a brief summary of each group member's tasks, contributions, and performance as a group member. It is the group leader's responsibility to organize the peer evaluation process to determine each group member's contribution grade (elaborated on Section IV.3). Note, the group leader should not assign a participation score without the input of the entire group.

Group members are responsible for timely communication with the group leader. If a student is assigned a task to complete with a deadline, the student should confirm that she/he will do so. If the student does not agree to the task or has difficulty with it and needs more time or help with the task, this should also be communicated to the group leader (well before the deadline).

II.3 Lab Reports

Each group prepares and submits one hard copy of the report, which is **due before lecture (i.e. by 1:00 pm) on Thursday, February 20, 2020**. Instructions for preparing this report are given in Section IV of this document. Grading weights are given in Addendum 1.

II.4 Individual Quiz

Each student also needs to watch a 10-minute video about the testing equipment and complete a brief quiz on Canvas. This quiz must also be completed any time **before lecture (i.e. by 1:00 pm) on Thursday, February 20, 2020**.

II.5 Torsion Machine Open House

KatieRae and the LAs will be holding optional "Open Houses" for students who want to ask questions and gain more hands-on experience with the MTS Torsion Machine. These Open Houses will be held in AERO 141C on Monday, Feb. 3 and Wednesday, Feb. 5 from 11:00 am - 2:00 pm and on Tuesday, Feb. 4 and Thursday, Feb. 6 from 3:00 - 5:00 pm. To attend, please sign up at `https://www.signupgenius.com/go/805084eabaf28abfd0-3112` to reserve your spot. Each Open House is limited to 7 students due to the capacity of the room.

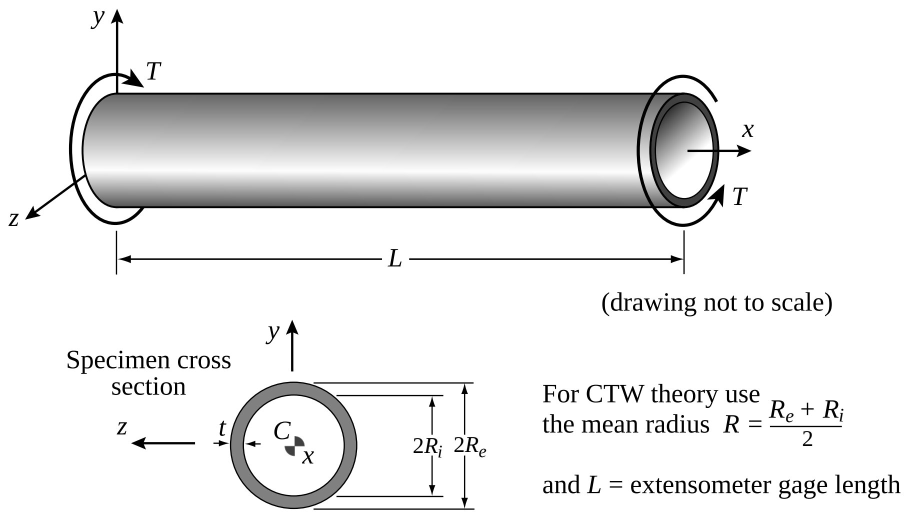

Figure 3. 1: CTW specimen: Torqued circular tube. Module grips are not shown.

III Experiment Description

III.1 Operational Instructions

Please refer to the operational procedures for the MTS Torsion Module in setting up the apparatus. The document *Experimental Procedure* can be found on Canvas in the *Lab 1* module.

III.2 The Closed Thin Wall Specimen (a.k.a. Closed Tube)

This specimen is identified as CTW, for Closed Thin Wall. It is the commercial circular tube depicted in Figures 3.1–3.2. It is also called the "closed tube" in the sequel for brevity. Nominal exterior dimensions are: exterior diameter $D_e = 3/4$ in, exterior radius $R_e = \frac{1}{2}D_e = 3/8$ in, and uniform wall thickness $t = 1/16$ in. For the test, L is taken as the extensometer gauge length in inches provided in the *Experimental Procedure* document. The material is stock aluminum tube. The shear modulus of this material is $G \approx 3.75 \times 10^6$ psi. **Note: English units are used throughout this lab.**

The specimen is instrumented with a torsional extensometer, as described in the **Experimental Procedure** document.

This specimen is to be subjected to torque levels from $T_0 \approx 0$ lbs-in (calibration level) up to $T_{max} \approx 400$ lbs-in. At that level the maximum shear stress reaches roughly 8620 psi, which provides a safety factor of about 2.3–2.6 against yielding. Three sets of measurements are to be recorded at increasing torque levels:

1. The shear strain γ in degrees over the gauge length of the extensometer. This strain may be converted to microradians (μ). If the strain is small (which can be assumed if the specimen is not taken beyond yield), the twist angle ϕ over the length L is $\phi = \gamma\, L/R_e$, where R_e is the exterior tube radius.

2. The total rotation applied to the specimen, as recoded by the testing machine.

3. The torque recorded by the testing machine.

III.3 The Open Thin Wall Specimen (a.k.a. Slitted Tube)

This specimen is identified as OTW, for Open Thin Wall. It is the same commercial tube used in the previous test with a longitudinal cut along its length. See Figures 3.3–3.4. It is also called the *slitted tube* in the sequel for brevity. Nominal cross section dimensions are the same as before. The cut width is to be assumed negligible compared to the cross section radial dimension. For the test L is taken as the extensometer gauge length in inches, which is provided in the *Experimental Procedure* document. The material properties are the same as those of the CTW specimen.

This specimen is to be subjected to torque levels in the range: $T_0 = 0$ lbs-in (calibration level) up to $T_{max} \approx 20$ lbs-in. **This range is much smaller than for the CTW specimen**. At that torque level the maximum shear stress is about 7800 psi, which provides a safety factor of approximately 2.8 against yielding. Note, however, that stress concentrations will occur at the slot ends, even after rounding the tips. The measurements of applied torque T and shear strain γ are like those described for the closed tube in Section III.2. The recovery of the twist angle, however, is different: $\phi = \gamma\, L/t$ instead of $\phi = \gamma\, L/R_e$.

IV Analysis and Report

IV.1 Report Organization

A hard copy of the Report is due Thursday, February 20, 2020, before lecture. **The report must be WORD or LATEX processed**. It must include:

- **Title Page**: Describes Lab, lists the name of the team members and identifies the group leader.
- **Results:** The results should address the questions in Section IV.2.
- **Appendix - Code:** A printout of all the code used to produce the results.
- **Appendix - Participation report.** More details on how the grade of individual group members is calculated can be found in Section IV.3.

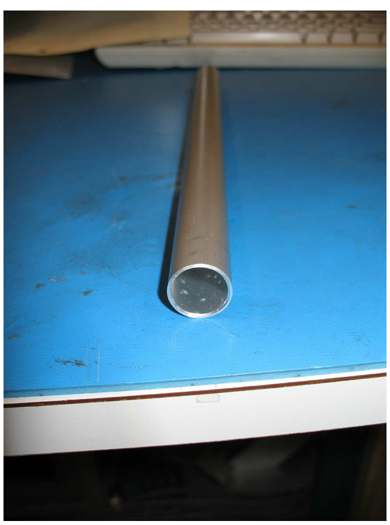
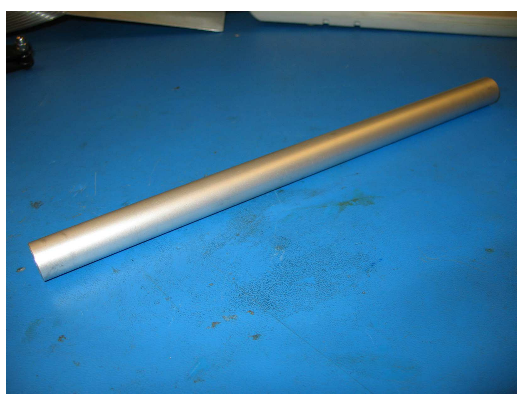

Figure 3. 2: Photos of CTW specimen. Module grips are not shown.

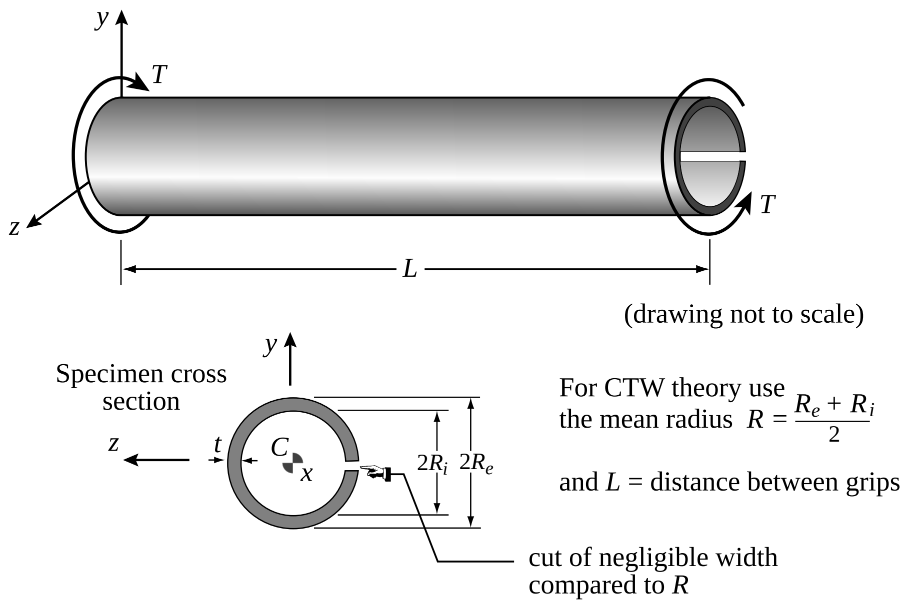

Figure 3. 3: OTW specimen: Torqued circular tube with longitudinal cut.

IV.2 Report Content

The report will be graded on both technical content and presentation. Regarding the content, instead of an open-ended report, you should process the experimental data to address the specific questions posted below. Regarding presentation, make sure that you follow these guidelines:

- All plots should be readable. This includes using different color or line styles and a suitable font size for the axis labels and all other text in the plot. The range of both axes should be chosen to focus on the region of interest (i.e., the data).

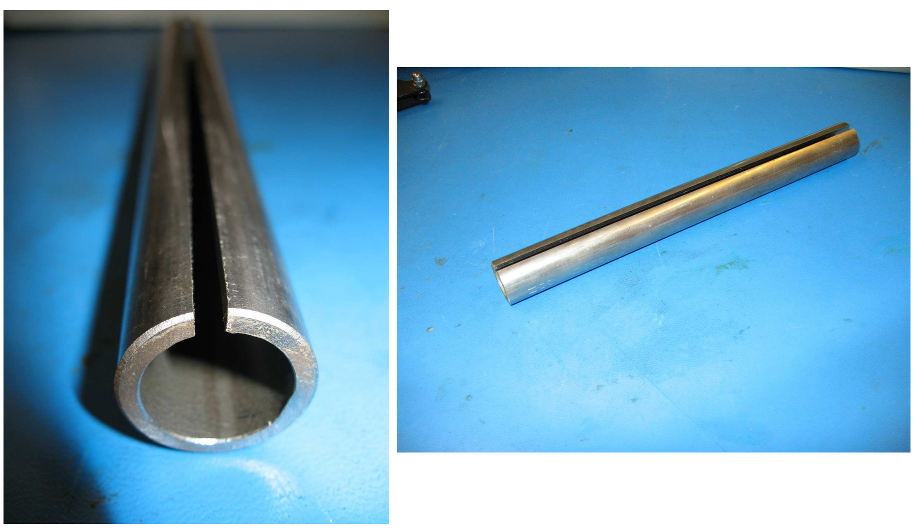

Figure 3. 4: Photos of slotted tube (OTW) specimen. Later replaced by one with 7-in-long slot to reduce grip end effects.

- Show your work, including equations used and partial results.
- All results should be presented with appropriate units.
- Be quantitative when comparing results. Use percentage of error or deviation. Refer back to predicted error or variance when applicable.

IV.2.1 Analysis of the Closed Thin Wall Specimen

- Plot the torque vs. shear strain provided by the extensometer, as well as the torque vs. shear strain calculated using the total rotation angle imposed by the testing machine.
- Use least squares fitting to calculate the torsional rigidity, GJ, for the two ways to obtain the shear strain. Provide the value of the associate uncertainty.
- Compare the value of GJ obtained through the experiments with the theoretical predictions obtained using exact theory and thin wall theory. Discuss the differences.

IV.2.2 Analysis of the Open Thin Wall Specimen

- Plot the torque vs. shear strain provided by the extensometer, as well as the torque vs. shear strain calculated using the total rotation angle imposed by the testing machine.
- Use least squares fitting to calculate the torsional rigidity, GJ, for the two ways to obtain the shear strain. Provide the value of the associate uncertainty.
- Compare the value of GJ obtained through the experiments with the theoretical prediction obtained using thin wall theory. Discuss the differences. Which important assumption could you re-consider obtaining a more accurate prediction?

IV.2.3 Importance of the Extensometer

- For both specimens, compare the values of GJ obtained using the shear strain provided by the extensometer and by the testing machine. Discuss the relative differences.
- Discuss at least two reasons that justify the need of an extensometer to ensure accurate results, instead of using the readings from the testing machine.
- An important part of engineering is choosing which sensor to use for a test you want to perform. Research another sensor or method for determining the shear stress in these two samples if you didn't have this extensometer and you didn't want to use the testing machine's readings. Discuss how this new sensor or method allows you to determine the shear stress, and discuss its advantages and disadvantages as compared to the extensometer. KatieRae and the LAs would also be happy to discuss this question at one of the Open Houses.

IV.2.4 Plastic deformation

Consider now the case in which the samples are tested beyond the elastic regime. Assume that the material behavior is elastic - perfectly plastic, with yielding initiating at shear strain γ_y, see Figure 5. The test response will then consist of three regions: a region where the whole specimen is still in the elastic regime, a transition region in which part of the specimen has plasticized, and a region in which all the material of the specimen has yielded.

- Sketch the expected response of the specimen in the form of a T - γ plot, where T is total torque and γ is the maximum shear strain in the specimen. Clearly identify the three regions.
- Assuming a closed wall specimen with length L, external radius R_e, internal radius R_i, and thickness $t = R_e - R_i$, provide the shear strain γ corresponding to the transition between the regions. Express the shear strain as a function of γ_y and the geometry of the sample.

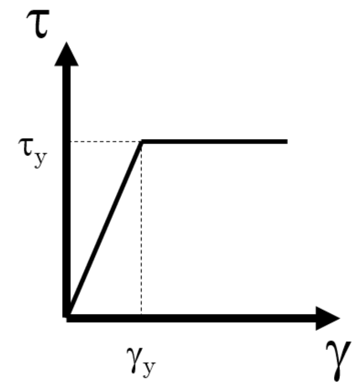

Figure 3. 5: Elastic-perfectly plastic material model. The shear and strain at yielding are τ_y and γ_y.

IV.3 Individual Contribution Evaluation and Deductions for No-Show

The group leader submits along with the report a separate participation report for your group with a brief summary of each group member's tasks, contributions, and performance as a group member. **Please make sure to include this as an Appendix in the report**.

The performance of each group member is rated with a "contribution factor" on a scale of 0 to 100%. A score of 100% indicates that the member contributed the expected share to the experiment and to the preparation of the report. The scores are normally assigned by *peer evaluation*, using the same procedures followed in the ASEN 200x sophomore courses. The group leader is responsible for administering the peer evaluation, tabulating and submitting the results of said peer evaluation.

The individual score will be equal to:

$$\text{Individual score} = \text{Group score} \times \frac{100 + \text{Contribution factor}}{200} + \text{Video quiz score} \tag{1}$$

For example, if the group receives an overall score of 78.75 and the individual received a "contributing factor" of 90% and a video quiz score of 8, the individual score is $78.75 \times (100 + 90)/200 + 8 = 82.81$.

A no-show at the lab demo, without justification, will be penalized by a deduction of 50% from the final individual score. Students that miss the demo on account of a bona-fide reason, such as a medical emergency or an academic-related activity, should contact the instructors as soon as possible.

Addendum I. Report Grading

The score assigned to the lab report includes technical content (75%) and presentation (25%). This is a more detailed breakdown of the weights:

Category	Points	Score	Contribution
Group - Technical content			
Question 1 Question 2 Question 3 Question 4	20 20 15 10		
Group - Report presentation			
Plots Grammar, style & spelling Formatting	10 10 5		
Individual - Video quiz	10		
Total	100		(overall score)

The points shown are the maximum number of points awarded for each category. The final score of each team member is then calculated following the procedure detailed in Section IV.3.