Lab 4 Strain Gage Application and Testing

rev S23

Objective

Learn how to install strain gages on specimens and apply them to bending and tensile tests.

Introduction

Strain gages are commonly used to measure strain changes on structural parts, which in turn allow us to determine, e.g. how external loads are distributed in the aircraft structure and the actual aerodynamic loads that occur during flight. In Week 5&6 lecture we have learned the basics of strain gages including how they are used in various Wheatstone bridge configurations for bending and tensile tests. In the next two weeks, we will put all the knowledge into practice. The task for first week (Lab 4a) is to install strain gages on both sides of an aluminum strip sheet. You will use all the tools and materials shown in Fig. 1 to do so. The process is a bit involved, so carefully follow TA's instructions and the application manuals (available from Canvas). The gages can be wired to observe bending (difference between front and back strains) as well as tension (average of front and back strains). In second week (Lab 4b), you will then perform such bending and tensile tests and make use of the data obtained from these strain gages.

Now it is time for you to "walk the walk" – you need to learn how to be a good technician before you can be a good engineer!

Figure 1. The tools and materials and the finished specimen with the strain gages installed.

References

[1] Week 5&6 lecture notes
[2] Strain gage application manuals (from Canvas)

Work to be done

1. Prelab

Week 1

(a) Look into Canvas under module *Misc* the three manuals:
Strain_gage_datasheet_SGD-5_350-LY13.pdf,
Strain_gage_technical_data.pdf,
Strain_gage_application_manual.pdf,
(b) Read through the strain gage information, technical data, and attachment procedure in general. Specifically look for gage Omega SGD-5/350-LY13 that we will use in this lab. Review Week 5&6 lecture notes as well,
(c) Make a brief checklist of strain gage installation procedure to yourself for use in lab. Be sure to include all steps involving surface preparation, gluing, and soldering,
(d) Review materials in this lab manual, Week 5&6 lecture notes and demo video.
(e) Work on week 1 prelab and submit to Canvas.

Week 2

(a) Again review materials in this lab manual, Week 5&6 lecture notes and demo video.
(b) Work on week 2 prelab and submit to Canvas.

2. In lab

As always, **you MUST wear safety glasses during the lab. Also be careful not to burn your fingers when do soldering.**

Our sample is made of 2024-O Aluminum alloy. The size is 2” x 8” x 0.025" thick. Its nominal value of Young's Modulus is 10600 ksi (or 73.1 GPa) and tensile yield strength is 50ksi (source: Matweb).

Throughout Weeks 1 and 2 labs, remember to take sufficient photos and draw necessary diagrams for later lab report writing.

Week 1-Lab 3a: Strain gage installation

(a) Obtain the aluminum specimen from TA. Double check the dimensions. Double check to make sure the protecting plastic film on one or both sides of the specimen has been removed.

(b) Prepare surfaces on both sides of the specimen through a series of degreasing (with degreaser), sanding (with sandpaper) and cleaning (with acetone and Q-tip) (Fig. 1). You need to closely follow TA's instructions as well as the application manuals.

(c) Mark clearly the center of the specimen on both sides of surface – these are the locations you will install the gages.

(d) Obtain a pair of strain gages from the TA, one at a time. Make note of the exact gage factor and resistance specifications. Remove one strain gage from the package and place it on the specimen surface you just cleaned. Make sure the side with terminals and lead wires is facing up. Orient the gage with the two lead wires running parallel to the long side of the specimen (Fig. 2).

(e) Cut a strip of the clear tape about two inches and make a tab on one end of the tape (which allows you to peel the tape off easy after gluing).

(f) Grab the two ends of the tape, orient the long side of the tape perpendicular to the long side of the specimen and have the tape centered right above the gage. Pick the gage up from the specimen surface by a light tap directly on the gage. Avoid tapping onto the lead wires.

(g) While still grabbing the tape ends, fine tune the tape position and orientation so that the gage (now attached on the tape) is directly above the marked center location of the specimen, and maintain the same orientation well as in step (f); that is, the two lead wires run parallel to the long side of the specimen. Tape down lightly the two ends of the tape to the specimen surface. Again avoid pressing onto the gage and the lead wires.

(h) Grab the tab that you made in step (e) on one end of the tape and slowly peel off the tape until the gage (still on the tape) just comes off the specimen.

(i) Apply one **SMALL** drop (we do mean small!) of glue from the 496 bonder to the specimen surface where the gage was located. Smoothly push the tape back onto the specimen.

(J) Evenly press down the gage through the tape for 2 minutes to secure a firm bonding. The lead wires should be made in upright position the whole time and no portion of the wires is glued onto the specimen!

(k) Grab the tape tab and peel off the tape slowly at low angle. Remove as much tape or glue residues as you can. Be careful not to touch the gage itself.

(l) Insulate the gage by taping the specimen surface area below the lead wires to prevent the gage's lead wires from touching the specimen (metal) surface.

(m) Cut two red thin (28 awg) electric wires about 18” long and strip about 1” from all ends. Make a small loop on one bare end and tie it to one of the lead wires of the strain gage to form a joint. Repeat to connect the other red wire to the second lead wire of the gage (Fig. 3).

(n) Start the soldering process by tinning the soldering iron. Then hold the solder in place on the joint and melt it with the tip of the solder iron (Fig. 4). Remove the iron and the joint will solidify. Once the soldered joint cools off, pull it slightly to ensure a good connection. If there is excess solder, remove it with a desoldering pump. Cut off all remaining bare ends of the connecting red wires as well as the lead wires of the gage. Wash hands to remove any residues of the lead solder.

(o) Protect the gage and the soldered joints by covering them with a strip of backside (not sticky) of tape. This can be done by taping a shorter tape strip under the longer covering strip with the sticky sides facing each other. This tape cover will allow the gage to expand freely underneath and prevent accidental damages to the solder joints and gage.

(p) Firmly tape down about one inch of the connecting wires (beyond the soldered joint) to the specimen surface. This will prevent the connecting wires from breaking off the gage accidentally.

(q) Test gage-wire connection with a voltmeter. The resistance readout should be within 1-2 ohm accuracy to the gage's nominal ohm specs.

(r) Repeat steps (d)-(q) for the other side of specimen using black wires.

(s) Once the gage installation is completed, write down your section and group numbers on the specimen and leave it to TA, who will store your masterpiece to be tested in the second week.

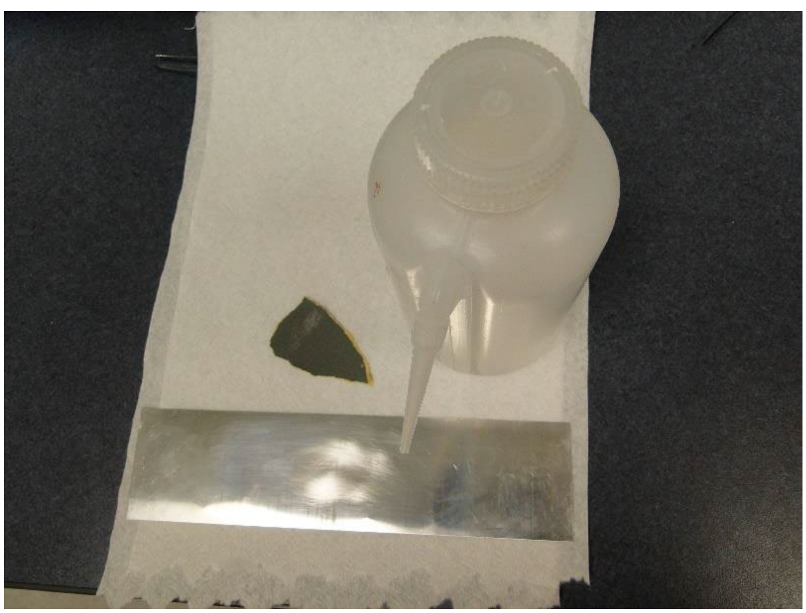

Figure 1. The process of preparing the specimen surface for gage installation

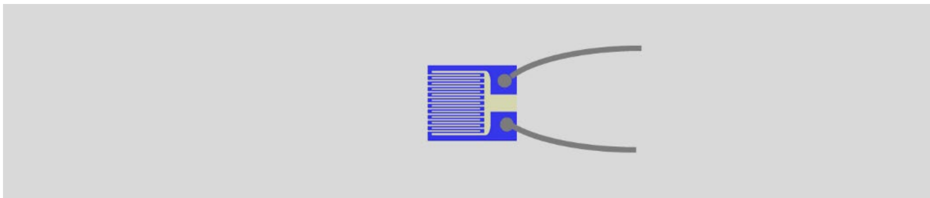

Figure 2. Gage placement and orientation on the specimen

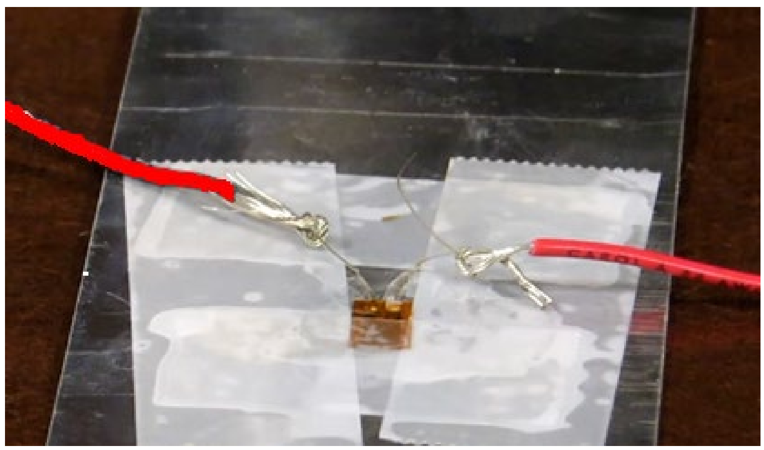

Figure 3. Make loops on the bare ends of the red wire and tie them to the lead wires of gage. Note that both connecting wires should be of same color.

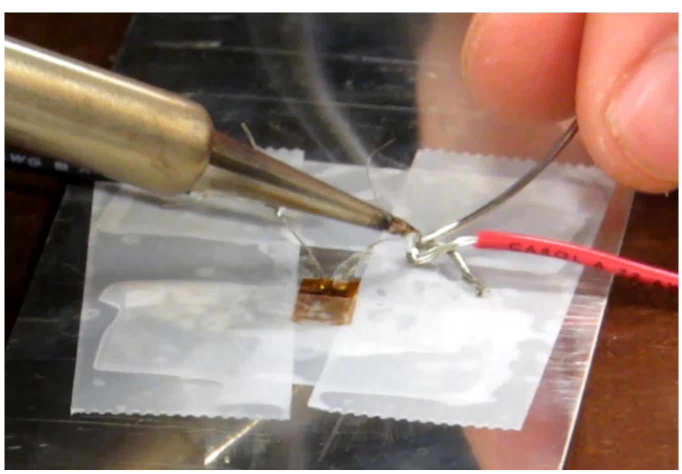

Figure 4. Solder the connecting joint between the red wire and gage leads

Week 2-Lab 3b: Mechanical Tests

Week 2 involves with mechanical tests of the aluminum specimen you fabricated in Week 1 with load/stress and elongation/strain data measured from the strain gages and the Instron dual-column load frame. The mechanical tests consist of a bending test done on a simple stand and a tensile test done with the Instron load frame. The goal is to determine the mechanical properties of the aluminum specimen.

Similar to other labs, a "strain gage application" child folder had been created within the "AerE 322" parent folder on the desktop of the controlling PC of the Instron load frame. Your section/group folder can be found further inside the "strain gage application" folder.

(I) Bending Test

We will first test the strain gages installed on the aluminum specimen via a three-point bending test as shown in Fig. 5.

(a) Connect wires from specimen to the wires from the yellow readout box (i.e. the Vishay P-3500 strain indicator) using the test clips: red to red and black to black.

(b) Verify the Wheatstone bridge configuration on the readout box. It should be a half bridge I gage-adjacent configuration (as learned from the lecture notes) with one gage measuring the strain on top side of specimen and the other measuring the bottom side.

(c) Try pulling (in tension) on the specimen by hand. Do you get any substantial change in the readout?

(d) Measure the span distance of the opening of the supporting wood plate edge-to-edge. Place the specimen across the opening and keep the gage in the middle of the span (Fig. 5). Make sure the specimen is placed on the wood plate freely with minimal pull or push by the wires in any direction.

(e) Turn the right balance knob on the readout box to balance the bridge as close to zero as possible. Use the left knob to switch to different level if needed (Fig. 6).

(f) Find a location on the specimen closest to the gage (as indicated by the downward arrow in Fig. 7) and place there the two or more small flat spacers (as provided on the bench table) around the gage, at least one on each side. Then put the weight (also provided on the table) on top of the spacers. Use the ruler to measure the vertical deflection of the specimen where gages are attached. This can be done by setting the ruler on the tabletop vertically against the edge of the specimen closest to gage's horizontal position and read out the height change before and after the weight is applied.

(g) Repeat step (f) several times and take average of the readouts. Remember to balance the bridge in each repeat.

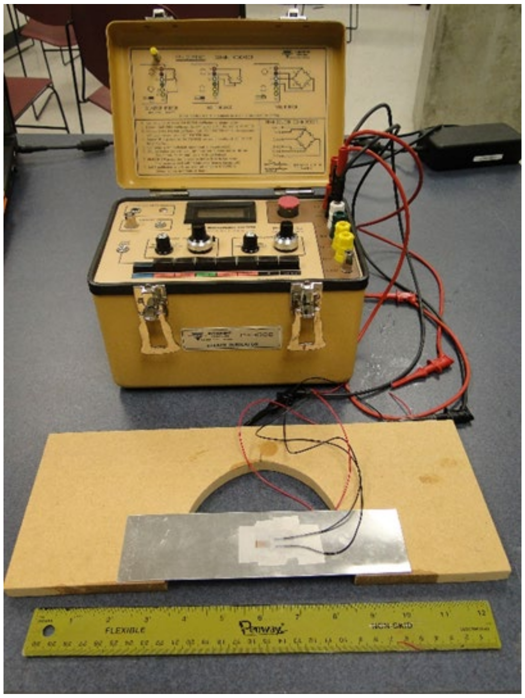

Figure 5. Bending test setup

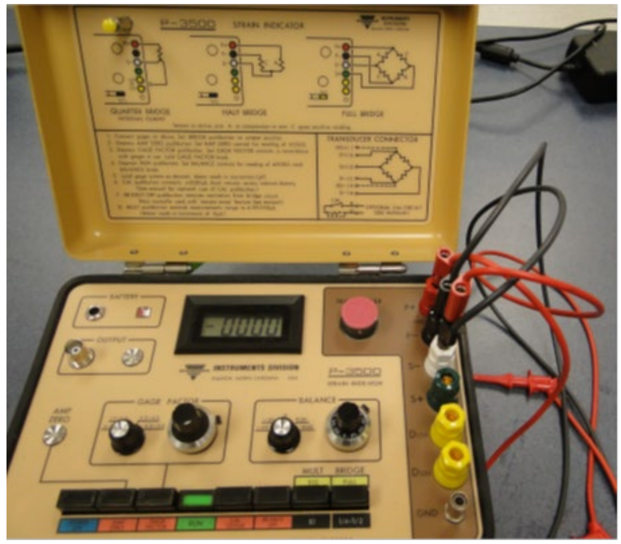

Figure 6. Wheatstone bridge configuration on the Vishay P-3500 strain indicator for the bending test

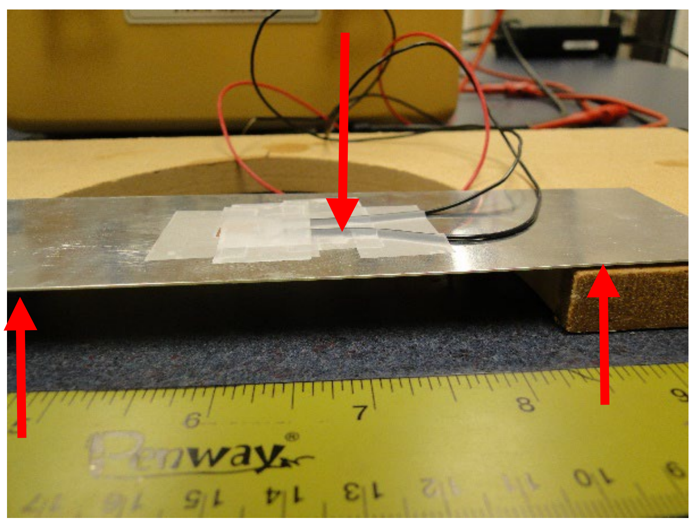

Figure 7. Three-point bending setup with external load applied at center

(II) Tensile Test

The second part of gage application is the tensile test performed in the Instron load frame station. The test begins with a series of manual calibration measurements using a thick and stiff steel plate about the same size of the aluminum strip sample. As described on pages 23-24 in Week 5&6 lecture notes, these calibration measurements are needed to reduce the excessive "system" elongation (mainly coming from the flat-end grips). The setup is shown in Fig. 8. After the calibration measurements are done, we can proceed with the tensile test (Fig. 10), in which two data sets are obtained simultaneously. First, the load vs. extension data are collected from the tensile test done in the load frame and plotted on the computer screen (right of Fig.11). At the same time, the strain changes at the gage are measured by the yellow readout box and output to a National Instrument USB-6000 data acquisition box. The digitized voltage (convertible to strain) vs. time trace is then displayed on the computer screen as well (left of Fig. 11).

(a) Fit the calibration plate into the flat-end grips of load frame (Fig. 8). As shown, the distance between top and bottom grips should be set so that each end of the calibration plate is fully clamped into the claw face. The grips have been aligned vertically, so just loosen the left screws of the top and bottom grips to allow the calibration plate to be fitted in (Fig. 8). Once the calibration plate is fitted and aligned between the grips, screw left grip back to the right. Tighten the grips the best you can to minimize "slip" on the claw face.

(b) Use the console pad to operate the load frame (Fig. 9). Press the button on the left (indicated by "1st" in Fig. 9b) and then the right ("2nd") to zero both the load and extension.

(c) Roll up the "fine position" knob (Fig. 9a) to increase the "system" elongation (extension) and load, click by click. Pause at each click to read out the load and extension readings and have another teammate record them. Each click will increase elongation by 0.00061inch and load by 80lbf approximately. At each new click, the load will initially overshoot then slowly decreases. Be sure to "catch" the load reading right after the initial overshoot (and before slow decrease starts).

(d) Stop step (c) when the load is above 400lbs, and the calibration measurements are completed. Remove the calibration plate and proceed with the tensile test of the aluminum strip sample with the gages installed.

(e) Like in the bending test, connect specimen wires to the yellow readout box. Follow the diagram taped inside the cover of the yellow box to set up the Wheatstone bridge configuration if not already done. We use two external resistors in the full bridge mode on the readout box to set up a half bridge II configuration (gages opposite) (Fig. 12). Make sure the Bridge Full button in yellow color is depressed.

(f) Try bending the specimen a little bit. Do you get any substantial change in the readout compared with that of the bending test?

(g) Fit your specimen into the grips of Instron frame. The distance between top and bottom grips should still be good for fitting both ends of the specimen into the claw face. Follow exactly the same procedure in step (a) to mount and dismount the strip sample. Also tighten up the grips to minimize slip at claw faces.

(h) Zero the load and extension readouts as was done in step (b). Roll up the "fine position" knob a few clicks (for about 50lbs load) to make the specimen straight and tight but not stiff (i.e. still having tiny wiggle room in the middle of specimen around the gage). Measure and record the length of the remaining specimen (not in the claws) between the grips. This is the so-called "gage length". Zero the load and extension readouts again.

(i) Click the Bluehill3 icon on top left corner of monitor desktop to open Instron's Blue hill3 software if not already running. Click the Balance All button on the top so that both load and extension read close to zero. Click the circular Test button on the lower left to bring up the Test dialog. "AerE 322 tensile_strain_gage.im_tens" should be highlighted near the top on the "Most recently used methods:" list. Click Next (right arrow) button on the right to bring up "Name the new sample" dialog. At the "sample name:" box, enter your section ID and group ID as the new name, e.g. "Section 1 Group 2". Then click the Browse button to navigate to your section/group location in "strain gage application" subfolder (within "AerE 322" folder) on desktop to store the data. Click Next (right arrow) button on the right to bring up the place holder for the load vs. extension plot. Reduce the Bluehill screen, drag it to the right and stand by. Make sure the Start (right triangle) button on the right is still visible.

(j) Balance the bridge on the yellow box as was done in bending test.

(k) Click "strain vs time from yellow box" icon on top left corner of monitor desktop to run the corresponding LabView software (Fig. 13). Further arrange the screen size of both the Bluehill3 and LabView software and their placement on the monitor desktop (Fig. 11). You are now ready to test.

(l) Click on Run (right arrow) button on top left corner of LabView screen (as indicated in Fig. 13), then immediately move to the Bluehill screen and click on the Start button. This starts the tensile test while monitoring the strain changes at the same time. The tensile test should run for 50 seconds and stop near 300lb load. When the test stops, immediately click on the Stop button (Fig. 13) in the LabView screen to terminate the data acquisition of strain from the gage. Likewise, click on Finish button in the middle right side of Bluehill screen to finish data collection by Instron station. Answer No to the "Start another new sample?" question. You should now see both load vs. extension plot in Bluehill screen and strain vs. time plot in LabView screen, as shown in Fig. 11.

(m) On the monitor desktop, look for the "strain_vs_time_yellow_box.csv" file, which contains the yellow box readout data in csv format. Similarly, go into "AerE 322" folder on the desktop to find the subfolder you just set to store the data. This folder contains the file "Specimen_RawData_1.csv" which has the load, extension vs. time data.

(n) Copy both "strain_vs_time_yellow_box.csv" and "Specimen_RawData_1.csv" to your own data storage device to be further processed later in After Lab. Otherwise, "strain_vs_time_yellow_box.csv" will be overwritten by next team's data! One last thing: look for the most updated value of a conversion ratio, which should be posted on the underside of the lid of the yellow readout box. This ratio will be needed in step (iv) in After Lab.

Figure 8. Calibration measurement setup

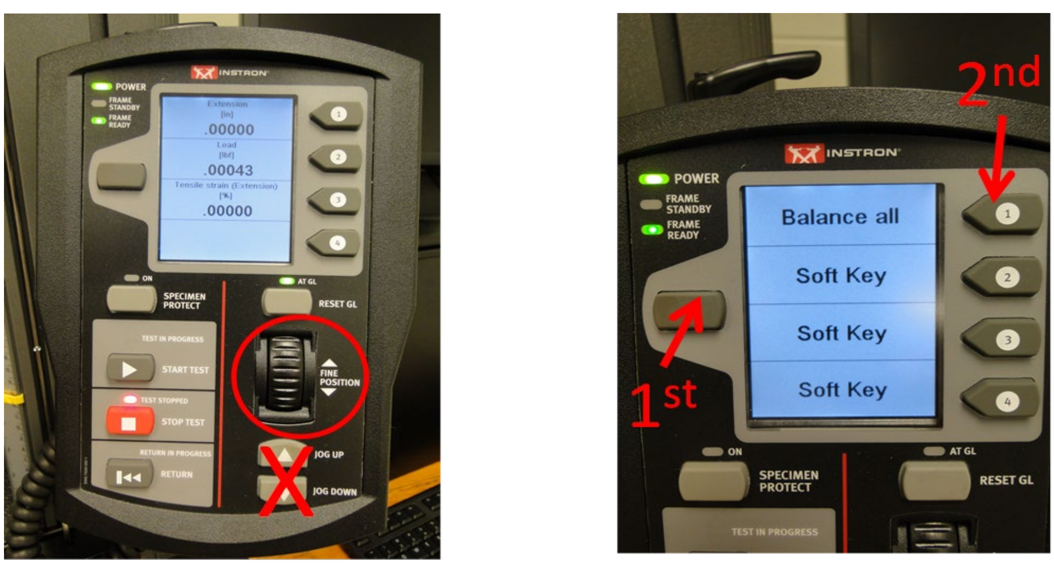

Figure 9. Control the load frame using console pad: (a, left) “fine Position” knob, (b, right) soft key buttons

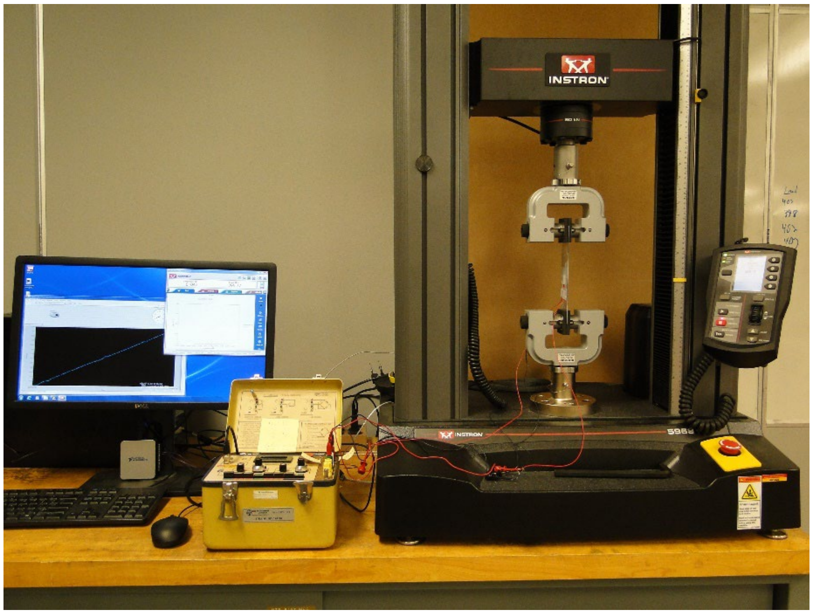

Figure 10. Tensile test setup

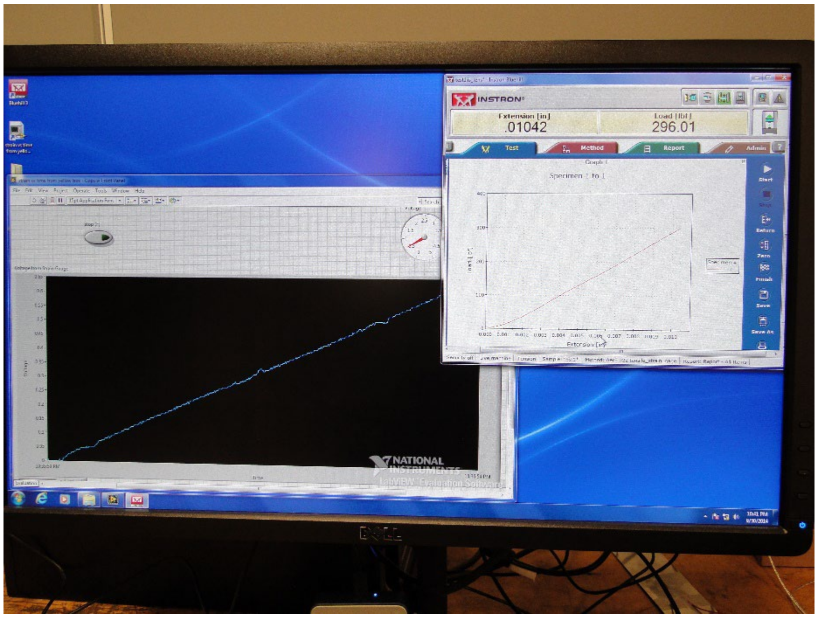

Figure 11. NI-6000 DAQ digitizes input from strain readout box and displays the strain-time plot (left) while Instron frame generates the load-extension plot (right)

Figure 12. Strain indicator's bridge configuration for tensile test

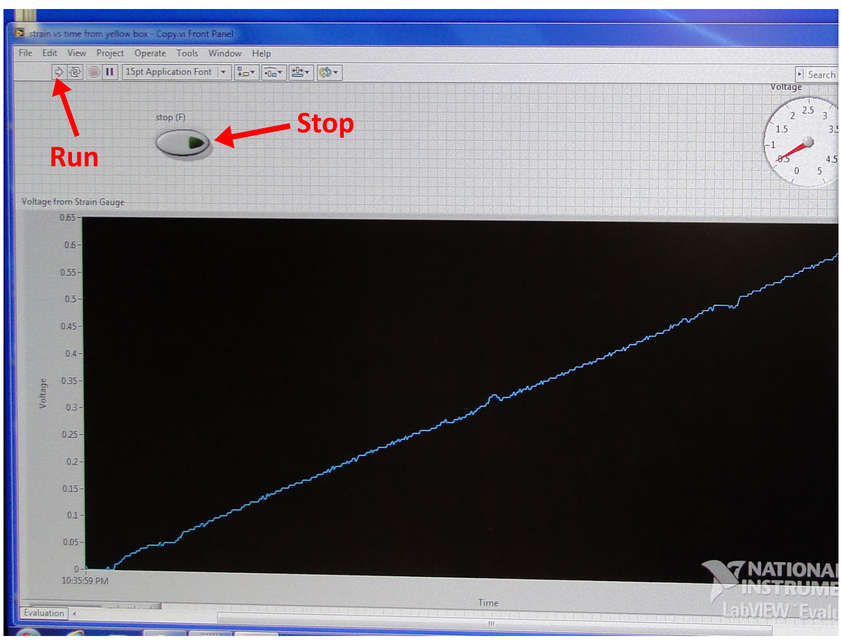

Figure 13. LabView software for recording strain at gage

3. After Lab

(i) (10%) In bending test step (c), explain why were (or weren't) you able to get any substantial change in the readout when pulling the specimen. Can you come up with a theoretical support? Hint: like in Week 5&6 lecture, apply the Wheatstone bridge equation (page 5) to a half bridge I configuration (page 8) but with like changes, i.e. both gages having positive increase in resistance. Work out the derivation.

(ii) (10%) In tensile test step (f), explain why were (or weren't) you able to get any substantial change in the readout when bending the specimen. How is the scale of change here in comparison with that of (i) above? Can you come up with a theoretical support? Hint: similar to (i), work out the results for half bridge II configuration (page 10 of lecture notes) but with opposite changes. That little theorem called binomial theorem (page 6) would be useful here. Compare this result with that from (i).

(iii) (15%) For the three-point bending test, can you work out a theoretical prediction for the strain and see if it agrees with the experimental data you obtained in In Lab bending test steps (f) and (g)? **Note that the readouts you obtained from the yellow readout box directly correspond to the strain**, equal to the left-hand side of the Wheatstone bridge equation divided by (βGF), i.e. $(V/E)/(\beta GF)=\varepsilon$ (see also Week 5&6 lecture page 14). These readouts are in microstrain, i.e. a reading of 1000 is actually $1000\text{x}10^{-6}$. Hint: Let us treat the aluminum strip specimen as a beam. The maximum vertical deflection in a three-point beam bending with central loading is given by $y_{max}=PL^3/(48EI)$, which occurs right in the middle span where load P is applied and the gages are located. Draw yourself a free-body diagram for the middle span and determine the bending moment M there. Then derive an expression relating y_{max} to strain ε (recall $\sigma=My/I$ and $\sigma=E\varepsilon$). The opening of the wood plate is about 13cm long that you have measured in lab, which would be your length L. Also recall the thickness of the specimen is 0.025 inch. Remember: do not rush to crank out the numbers on your calculator or PC right away – wait until you derive the final expression.

(iv) (5%) For the tensile test, convert the strain gage readout from yellow readout box (via NI USB-6000 data acquisition box) into microstrain. Each column value in file "strain_vs_time_yellow_box.csv" measures the microstrain at each time instance in the ratio around 0.25 per 1000 microstrain (i.e. a value of 0.25 in the file is converted into a value of 1000 in microstrain). On the day of lab, you should have obtained the most updated value of this ratio posted in the underside of the lid of the yellow readout box. Also recall that the strain gage reading (from NI USB-6000) is from a full bridge setup to work as a half-bridge. So **all the strain gage readings need to be divided by 2 after they are converted into microstrain**.

(v) (10%) For the calibration test data you obtained in tensile test step (c), plot the system elongation (as vertical axis) vs. the load (as horizontal axis). Like what you did in Lab 1, fit a straight line through the data points as described on page 24 of Week 5&6 lecture notes. Using this linear model, you can compute the system elongation (extension) for any given load for tensile tests done in similar load range.

(vi) (10%) Correct the extension reading from load frame (file "Specimen_RawData_1.csv") by removing the system extension error. This can be done by plugging the load values in file "Specimen_RawData_1.csv" into the linear model of step (v) and computing the corresponding system extension for each load value, and then subtracting these system extension errors from the extension values in file "Specimen_RawData_1.csv".

(vii) (10%) Convert the corrected extension readings from step (vi) into average strain (in microstrain) by dividing the corrected extension by the gage length, i.e. the distance between grips. Then convert the load readings into stress (say in psi). Remember the specimen width is 2" and thickness is 0.025". Plot the strain vs. stress and fit a straight line to the data.

(viii) (10%) Plot strain gage reading from step (iv) and average strain from step (vii) together. You will need to line up the times from NI USB-6000 with the times from the load frame. For that, you should smooth (remember what you did in Lab1?) and trim the two ends of the data in file "strain_vs_time_yellow_box.csv". Also note that load frame sampled 10 times per second, and NI USB-6000 sampled 100 times per second.

(ix) (5%) Where do average strain and strain gage reading differ from each other? Why?

(x) (10%) Assuming the stress increase is linearly proportional with time, convert the time scale of strain gage reading (from NI USB-6000) into stress which should match with the stress values you converted from loads in step (vii). Plot the strain vs. stress and fit a line to the data.

(xi) (5%) Estimate the experimental Young's modulus from the fitted lines from the two strain vs. stress plots obtained in steps (vii) and (x), and compare them with the nominal values (73.1 GPa or 10600 ksi).

4. Report

Formal full report as before. Make sure you answer all questions in the After Lab section!