

Stress-Strain Data with EXCEL

Welcome to the Mechanical Testing Instructional Lab (MTIL).

The gears can be a little rusty at the start of a new semester and new material can be a bit unnerving. The processing of data from MTIL experiments may be the first time that you have analyzed large sets of real data. This narrative will help you get started on the lab reports by providing step-by-step instructions for converting an Instron data file to a stress-strain curve. Additionally, a list of helpful EXCEL commands is included to make data reduction and report assembly more efficient. By no means does this information tell you everything you'll need to know, but provides assistance in constructing a curve you will get to know *very* well during the semester. You will also discover a plethora of extra tricks in WORD and EXCEL as the semester progresses, so take advantage of the group setting to learn from your classmates!

The Tensile Test

This example uses data recorded during tensile testing on an Instron testing machine. The specimen is made of 6150 Steel. During the test, the load increases to a maximum value, then decreases. Eventually the specimen breaks.

Information about the specimen and testing conditions are recorded in a header file. Data are recorded during the test. We are primarily interested in the tensile load and the corresponding relative change in length, linear strain. The data are used to generate a stress-strain curve.

Download the Data

Get started by retrieving data files from the server at:

<http://mtil.illinois.edu/DATA>

The raw test data are accessed in your class directory (or /MTIL666) in 00-TensileExample. Display the file in a browser, then right-click to "Save Page as ...". Files generated during testing are in ASCII tab-delimited format and have the extension *.txt*. The stem, "EXC6150", is entered at the time of testing. The header file, designated by *_h.txt*, lists test parameters such as the specimen diameter and the crosshead rate. The data file, designated by *_d.txt*, contains the data for load and strain as well as crosshead displacement and time. Download both test files to your hard drive. They will be available to start over in case of an error. For convenience, put all files in a folder (directory) such as "My Tensile Example".

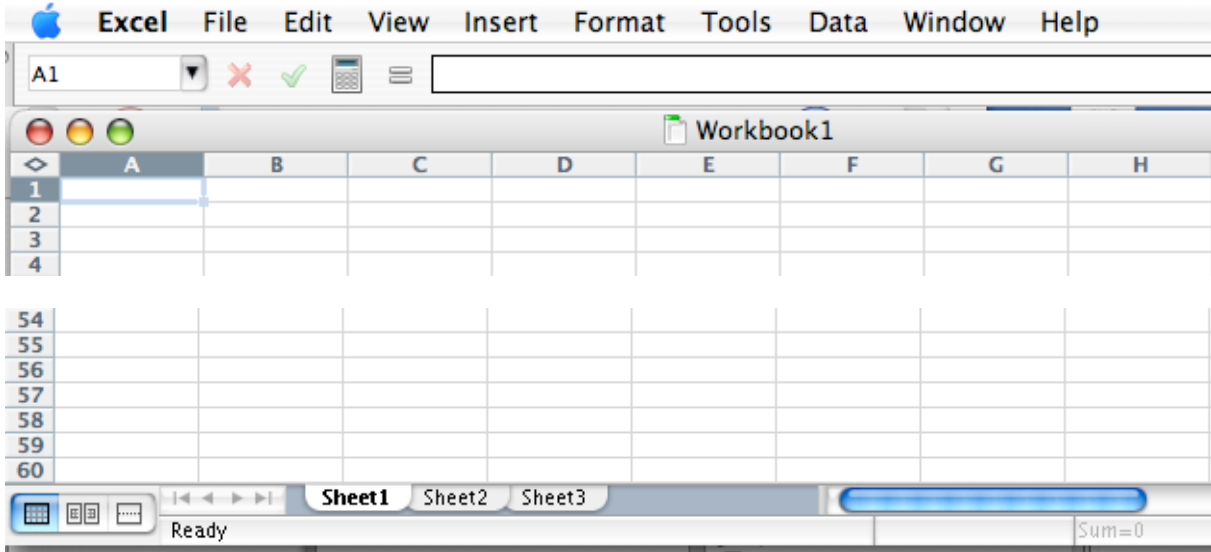
About Using EXCEL

The following procedure is not the *only* way to process data. Part of the "philosophy" here is that all data from a test are placed on a single worksheet and processed. Other worksheets may be used for different tests. Specific techniques may vary for different versions of EXCEL.

Assistance is available by selecting Help on the menu bar. For more complete descriptions of engineering applications in EXCEL, see the references at the end. When using search engines, begin the entry with “EXCEL”, your platform and version.

New workbook

Open a blank workbook. Go to Sheet1. (See the tabs at bottom of the window). Be sure that the formula bar is displayed at the top of the screen. The formula bar has the cell address in the Name Box and its contents. (View>Formula Bar)



In cell A1, type a title – “Tensile Example”, press *Enter*. In A2, “6150 Steel”. A title can help to locate a reference quickly when you are working with data from many tests. Move to the title in the bottom tab, “Sheet1”. Double click or right-click to rename the Worksheet as “6150Example”. In future assignments, you may want to analyze each material (or test) on a separate worksheet.

Save your file. Helpful hint: Save your data periodically to a new filename. Keep the same basic stem, but progressively number as Steel6150Tens#1.xls, Steel6150Tens#2.xls, etc. If a major error is made, you can step back to a “good” saved version.

Enter the header data.

Highlight a cell in column A, a few rows down from the title. [Mouse over to the cell and click or move with the down arrow (↓)]. (In the example, the cell is A4.) Go to your data directory and open the EXC6150_h.txt header file that you downloaded. Select ALL, and then Copy. Go back to EXCEL and paste these data into the worksheet. Increase the width of column A to see full descriptions. (Double click on the border between the column headers, “A” and “B”. Column A will expand to display the widest entry in the column.)

Enter the test data.

On your worksheet in column A, highlight a cell that is a few rows down from the last line of the header file (A30 in the example). In your data directory, open the EXC6150_d.txt file, select ALL, copy, and paste into the worksheet. NOTE: the * is an indicator for some programs that the next row is a header row.

A Note on Importing Data

The files generated in the lab are tab-limited so that they easily paste into the worksheets. Importing data using Data>Get External Data> is not required. You should have something similar to:

The screenshot shows an Excel spreadsheet with the following data:

Row	Column A	Column B	Column C	Column D	Column E	Column F
1	Tensile Example					
2	6150 Steel					
3						
4	Program name:	4400test v01-1				
5	UGlab ID:	Instron#A:LV Programs:MTIL				
6	Test Type:	Tension				
7	Date:	Thu, Sep 5, 2002				
8	Time:	10:14 AM				
9	Course/Section/Group:	MTIL666/S/E				
10	Material tested:	6150 Steel Cold Rolled				
11	Specimen Info:	99 HRB				
12	Specimen diameter:	6.37 mm				
13	Measurement interval:	1 sec				
14	Crosshead direction:	Up				
15	Crosshead speed:	2 mm/min				
16	Compensation factor:	1				
17	Full-scale load:	100 kN				
18	Full-scale strain:	100 percent				
19	Peak load:	2.13E+01 kN				
20	Extension at peak load:	9.69 mm				
21	Strain at peak load:	0.1592 dimensionless				
22	Load at onset of break:	1.82E+01 kN				
23	Extension at break:	12.39 mm				
24	Strain at break:	0.2655 dimensionless				
25	FINAL dimensions:					
26	Diameter:	4.69 mm				
27						
28						
29						
30	*					
31	Position(mm)	Load(kN)	Strain(-/-)	Time(sec)		
32	0	8.59E-02	0.000054	0		
33	0.03	2.55E-01	0.000054	1		
34	0.07	2.82E-01	0.000054	2		
35	0.1	2.95E-01	0.000054	3		
36	0.13	3.09E-01	0.000054	4		
37	0.17	3.17E-01	0.000161	5		
38	0.2	3.28E-01	0.000295	6		
39	0.23	3.44E-01	0.000215	7		
40	0.27	3.62E-01	0.000134	8		
41	0.3	3.89E-01	0.000268	9		
42	0.33	4.22E-01	0.000349	10		
43	0.37	4.56E-01	0.000322	11		
44	0.4	4.89E-01	0.000188	12		
45	0.43	5.21E-01	0.000242	13		
46	0.47	5.48E-01	0.000295	14		
47	0.5	5.75E-01	0.000215	15		
48	0.53	6.01E-01	0.000242	16		
49	0.57	6.31E-01	0.000322	17		
50	0.6	6.55E-01	0.000403	18		
51	0.63	6.79E-01	0.000295	19		
52	0.67	7.01E-01	0.000268	20		

The EXCEL workbook Steel6150Tens.xls containing a completed example is located in the HELP folder.

Formulas and References – Relative and Absolute

Formulas start with “=”. Remember that when a formula is copied, the cell addresses change. This is one of the most powerful features of spreadsheet programs. When the formula in C32, “=A32 * B32”, is copied to cell C33, it becomes “=A33 * B33”, and so on

down the column. The value in column C is the product of the values in columns A and B in the same row. This task is an example of a *relative* reference; wherever the cell is copied, the result is the product of the values in the two cells to the left of it.

Often, an operation is performed on many cells with a constant value. To compute engineering stress, the load in each row is divided by the original cross-sectional area. One method (not recommended) is to type the calculated area in the formula. It is a better technique to use the address of the cell that contains the area data. To make a reference *absolute* (constant), place “\$” in front of the column and row. For the example above, “ $=\$A\$32 * B32$ ” copied to C33 results in “ $=\$A\$32 * B33$ ”. This feature may be used efficiently in our example. First compute the cross-sectional area and make the cell address a constant divisor in the formulas employing the “\$” designations.

Another way to specify a constant is to name the cell. This is especially convenient when many different data sets are being analyzed. In the current sheet, locate “Specimen diameter:” in Column A (A12). Highlight the adjacent cell in column B (B12). From the menu bar (top of screen), choose Insert>Name>Define. Excel may suggest a name based on column A. Since there may be more than one 6150 steel specimen, call this one “Stl6150a” and add “diameter”.

Position (mm)	Load (kN)			
0	8.55			
0.03	2.55			
0.07	2.85			
0.1	2.95E-01	0.000054		3
0.13	3.09E-01	0.000054		4
0.17	3.17E-01	0.000161		5
0.2	3.28E-01	0.000295		6
0.23	3.44E-01	0.000215		7
0.27	3.62E-01	0.000134		8

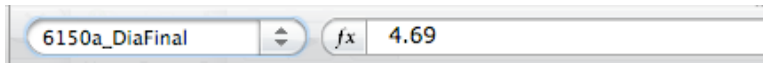
Name: Stl6150a_diameter (highlighted); cell address = B12 in the current Sheet (bottom of the Define Name frame.) (Note: Names are not case sensitive.) Click OK. Note that the Name Box on the formula bar now displays the name rather than the column and row.

Accessing the Define Name window is the only way to delete names and edit their ranges.

Names may also be entered on the Formula Bar. The final diameter is displayed in cell B26. The formula bar displays the cell address in the Name Box and contents.



Type the desired name in the Name Box and press *Return*.



An entire range of cells may be highlighted and assigned a name in this manner. Names and their ranges may not be edited using this technique.

NOTE: Names must start with a letter or underscore, but may not be the same as a possible cell address. The most recent versions of EXCEL designate cell addresses using up to 3 letters and 7 digits, *e.g.*, *abc1023456*. Therefore, “Stl6150” and “Al2024” are invalid names. Some valid alternatives are “Stl6150a”, “_Stl6150”, “Steel6150”, “Stl_6150”, and “Al_2024”.

Pi

The constant, pi, is PI(). Note the *empty* parenthesis. A good technique is to enter functions in lower case. If the formula is correct, EXCEL converts it to caps. If not, it remains in lower case indicating an error.

Area

Arrow right (→) to cell D12 and type in “Area:”. Set this label to align right with Format>Cells>Alignment, Horizontal: Right. In column E enter the formula for area, $\pi d^2/4$. Start the formula with “= pi() *”. To enter the diameter, click on the cell you just named (Stl6150a_diameter). Square with “^2”, then divide by 4 (“/4”). The result is:

$$= \text{PI}() * \text{Stl6150a_diameter}^2 / 4$$

Name this cell (E12) “Stl6150a_area”.

Type the units “mm^2” in column F.

The use of names may appear to be trivial here. When large amounts of data are compiled, names can be very useful. For example, data, including diameter, from 15 tests could be summarized in a table on the 17th spreadsheet of the workbook. For the test 6150a, simply enter the formula “=6150a_diameter”. The process may be streamlined with database functions, so that the diameter for each test will (*nearly*) automatically be reported in the table.

Your completed worksheet can be copied as a new worksheet, and then data from another test can be pasted. Since the data formats are the same, the new diameter is in the right place and the corresponding area and other formulas are immediately recalculated.

Now stresses can be calculated. Find the label “Time (sec)” in column D. On the same row, in column E (E31), enter “Stress (MPa)”.

Definition of units of Stress

$$1 \text{ Pa} = \text{N/m}^2$$

Or,

$$\text{Stress (Pa)} = \frac{\text{Load (N)}}{\text{Area (m}^2\text{)}}$$

$$1 \text{ MPa} = 10^6 \text{ Pa}$$

$$1 \text{ mm} = 10^{-3} \text{ m}$$

$$1 \text{ mm}^2 = 10^{-6} \text{ m}^2$$

$$1 / \text{mm}^2 = 10^6 / \text{m}^2$$

Therefore,

$$\text{Stress (MPa)} = \frac{\text{Load (N)}}{\text{Area (mm}^2\text{)}}$$

Note that the test load (column B) data are recorded in units of kN (1000N). Therefore,

$$\text{Stress (MPa)} = \frac{\text{Load (kN)}}{\text{Area (mm}^2\text{)}} * 1000$$

Enter the formula (Stress =.....)

In the Stress column (E), highlight the cell below “Stress(MPa)” (E32). Start the formula with “=”. In the same row, click on the load value (B32). Then type “* 1000 /”. Click on the cell with the area (Stl6150a_area). For the cell E32, the formula is:

$$= \text{B32} * 1000 / \text{Stl6150a_area}$$

Stl6150a_area is an absolute reference (constant). The load (Column B) is a variable.

Copy the formula to derive stress from the load data

Copy the formula in E32 down the column to the last row of data.

One way to copy the formula down the column is to highlight the cell to be copied (E32), and then move the cursor to the bottom-right corner of the cell. Note that a “+” sign appears. You may copy the formula by dragging this corner down the column. That is a long drag! There must be a better way!

When the “+” sign appears, double click on it. The column will be filled until an empty cell in column B is encountered. Scroll down the column with the down arrow (↓). Note the display of the formula for different cells in the formula bar.


Save your work.

Plotting the Data

There are a lot of numbers organized in columns. “A picture is worth a thousand words” or a whole table of numbers!

Next, we will create a graphical image of the data. In EXCEL, plots (graphs) are called Charts. (Perhaps, because the spreadsheet is rooted in accounting?!) Select the two columns of data. Click on the letter at the top (column label) of the strain column to highlight the *entire* column (C). Press and *hold* control [command (⌘) for Mac], then click

the top of the stress column (on the “E”). Both columns are selected and highlighted. (Column D is *not* selected.) Depending on the version, click on the Gallery icon, then

Charts or select Chart Wizard  on the toolbar. Choose ‘XY (Scatter)’, then select *points only*. [NOTE: **Line charts** are designed for equally spaced data. **Do NOT use here!!!**]. The details of your display may be different from this presentation.

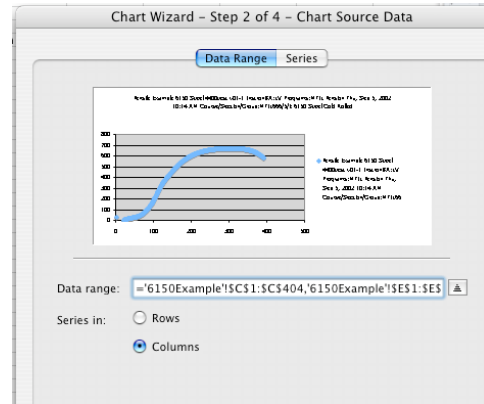
Note: In general, use only points with no lines for experimental data and lines with no points for correlations and theoretical constructions.

If you get only a plot, right-click on the chart and then Select Data.

Click Next> if available.

The *Range* contains ALL of the charting (plotting) data. *Series* contain data for individual plots. For this test, the “Series in:” choice is

● Columns.



The initial selection was *all* of column C and *all* of column E, so the range starts at row 1. Useful data start at row 32.

In the Data Range box, change the \$1 references to \$32 for both C and E to get:

=’6150Tens!’\$C\$32:\$C\$404,’6150Tens!’\$E\$32:\$E\$404

The X and Y scale ranges will adjust automatically.

Click Next> if available.

Enter title (Steel 6150 – Stress-Strain) and axis labels (Strain and Stress (MPa)). Note that a preview appears in the window.

Press Next>.

Have the chart appear in the same worksheet. Press Finish>, then Save the workbook.

On recent versions, changes are performed using the Formatting Palette. If the palette is not visible, select View on the top menu bar, then Formatting Palette. Chart Options and Chart Data are the most useful.

It’s okay, but it needs work. Save!

Extraneous Data

There is a point around Strain = 0.08, Stress = 0 that does not belong to the test. Between the time that the test computer requested data from the testing machine and the time the machine reported data, the specimen failed. This point is not part of the test and must be eliminated.

Eliminate the point by deleting the data in the cells on row 404 or delete the entire row. To find the last row, click on a cell within the recorded stress-strain data, and then press *End*, then arrow down (↓). The last data entry in the column is highlighted. Delete the data or the entire last row. Ascertain that the point has vanished from the graph.

Improving Appearance

A good plot helps you understand the data and is a major tool communicating your message in a report. The emphasis is on clarity rather than artistry. Use only one or two fonts. Avoid wild color schemes.

Improve the readability of the Y-axis by using the Number format with no decimal points. The graph should be positive for all data. To adjust the axes, right-click on any number label to pop up “Format Axis.” Set the Scale for a minimum value of 0. Adjust the maximum if necessary. For “Number”, select “Number” (rather than “Scientific”) and decimal places = 0. UNcheck “Linked to Source.”

The X-axis may be displayed as recorded in non-dimensional units. Right-click a number label. Set the minimum to 0.

Usually, strain is reported in percent (as on the Instron display). Set the number format for the X-axis as Percent with decimal places = 0.

The menu bar Chart or the Formatting Palette allows entry of Titles for the chart and axes under Chart Options.

For this plot of one set of data, there is no need for the legend. Select the chart (changes to a darkened border). The “Chart” option appears on the EXCEL menu (top), select Chart>Options>Legend. (Alternatively, right-click in the chart area.) Select “Legend” and UNcheck Legend. On the Formatting Palette, use Chart Options.

We have chosen to display discrete points rather than points joined by lines. Large markers tend to obfuscate the details of the experiment. Right-click on the plotted data points to “Format Data Series”. (This selection is distinguished from “Format Data Point”). The “No Line” Option should already be chosen. DEselect “Shadow”. Choose a point shape and make the point size as small as possible.

After the plot is complete, most options may be accessed with a right-click on the graph. Or use the Chart menu at the top of the screen. The Chart Formatting Palette may be displayed by clicking on Toolbox or by using the View option.

Save your work.

Experiment with the various chart options: Colors (Foreground and Background) for Series and the chart itself, Grid lines, Tick marks, Number formats, Fonts, Scales, Markers, Stretch the size (internal grid and entire chart window), etc. Create the good, the bad and the ugly!

Try this. Left-click on the last data point of the series. “Format Data Point” will pop up. Choose “Show Label”. On the chart, highlight the displayed label, and type in “X” to indicate fracture. Under Format Data Labels, set all alignments to “Center.” Adjust the size to make it obvious. Alternatively, format the point with an “x” shaped marker.

A few items to notice on the curve: important engineering features include (a) the linear elastic region, (b) the yield point, (c) the ultimate tensile strength (UTS), and (d) the failure point.


About Reports

Remember that table headings go *above* the table and figure captions go *below* the figure.

Always make sure that when multiple curves are on the same figure, the lines/symbols are independent of color. The report might be printed or copied on a non-color device, so the figures need to be explicable even in black and white.

Hints – Learned during the course

Some EXCEL tips:

- Ctrl + Home takes you back to cell A1.
- Arguments of a function must be enclosed in parentheses [*e.g.*, ln 10 is =ln(10)].
- Trigonometric functions use radians as their argument!
- DEGREES(angle) converts radians to degrees and RADIANS(angle) converts degrees to radians.
- Pressing *End* then an arrow key navigates along a column or row [depending on which arrow key you use]. Starting in an empty cell, the first occupied cell is found. Starting within a series of occupied cells, the last occupied cell is located.
- Holding the Ctrl key while selecting cells with the mouse allows you to select individual cells anywhere in the worksheet.
- Holding the Shift key while arrowing in any direction selects cells like dragging the mouse—this also conveniently allows you to *deselect* cells, for instance if you accidentally selected one too many cells in a long column of data.
- Alt + Shift + F1 inserts a new worksheet.
- From the menus select Insert>Comment to add a comment to a cell. This helps your worksheet organization and allows any user to understand the purpose of the cell.
- Window>Freeze Panes is used to keep column or row headers stationary while the data are scrolled.
- “New Window” opens a new frame to navigate separately in the worksheet. You *can* be in two places at once! Remember that a change in one window affects both views.
- The function icon  opens the formula toolbar to see all built-in functions.
- Referencing cells in a different sheet: to reference cell D7 in Sheet 2 from another sheet use =Sheet2!D7. Or use its name!
- A “circular reference” warning means you referenced a cell to itself. Use the trace tool to analyze.
- Right click on a cell to add comments to document your procedures.

References

S. C. Block, *EXCEL for Engineers and Scientists, 2nd Ed.*, Wiley & Sons (New York), 2003.

J. P. Holman, *What Every Engineer Should Know About EXCEL*, CRC Press (Boca Raton), 2006.

Credits

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