Dureza
(Indentation Curve Analysis Software),
by D. Shuman and A. Costa

Reference paper:
Shuman DJ, Costa ALM, Andrade MS. Calculating the elastic modulus from nanoindentation and microindentation reload curves. Mater Charact. 2007; 58(4):380-389

Help File

MENU Topics:

File:
Import (.TXT; .CSV)
Open (.DRZ)
Save As (.DRZ)
Save
Save As

Print
Exit

Edit:
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Clean

Analysis:
Elastic Modulus
Hardness

Graininess Functions:
Shows the change in displacement along the unloading or reloading curve.

Help:
Help
About

Import Indentation Files (.TXT; .CSV)

First enter the line number where the displacement and force data start. Then select the data separator type. The edit
box will show a double line (||) where it found a separator. Then select the correct units and column number for the data.
The time and segment data are optional, click the check box if you want them to be imported.

SAVE .DRZ:

The save as unload function automatically separates all of the unload curves from a series of load unload curve cycles or steps. This function will display a message box with the number of curve files saved.

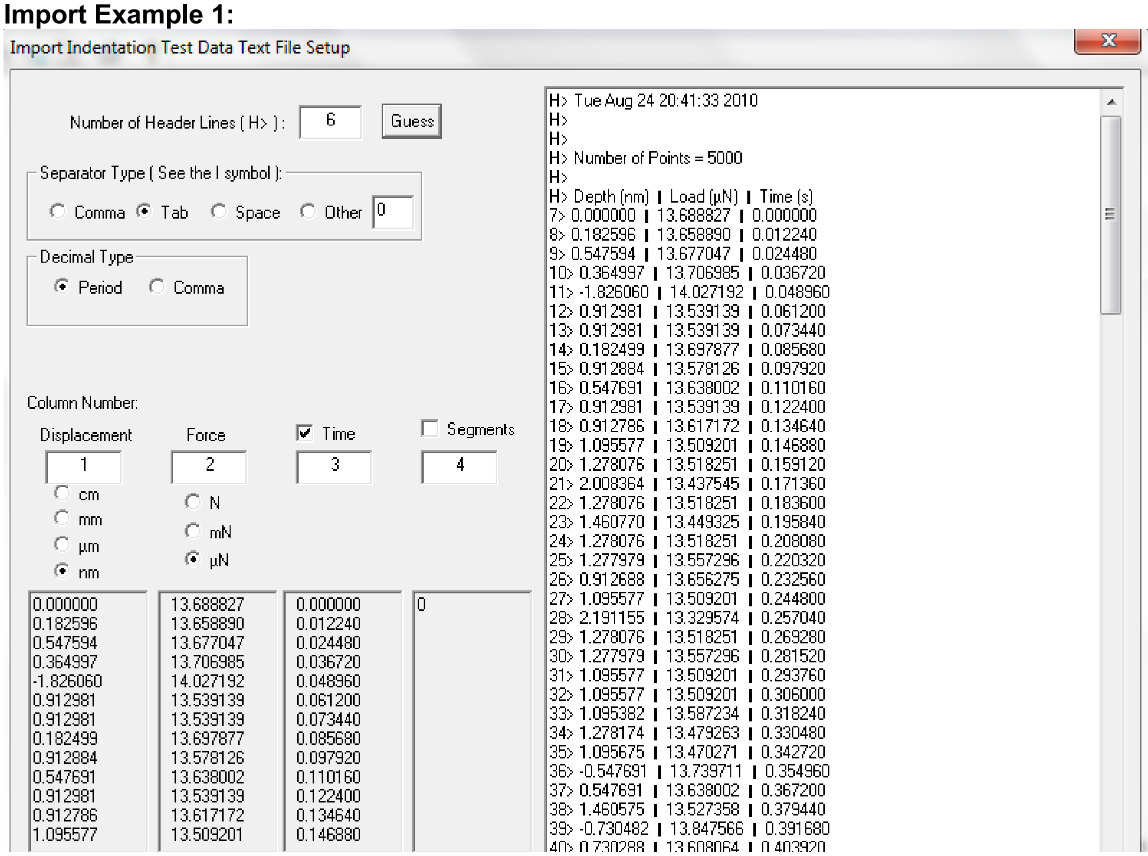
Examples of Importer File Formats

This function opens the standard comma seperators (.CSV) text files that were save as using the Dureza save as function.

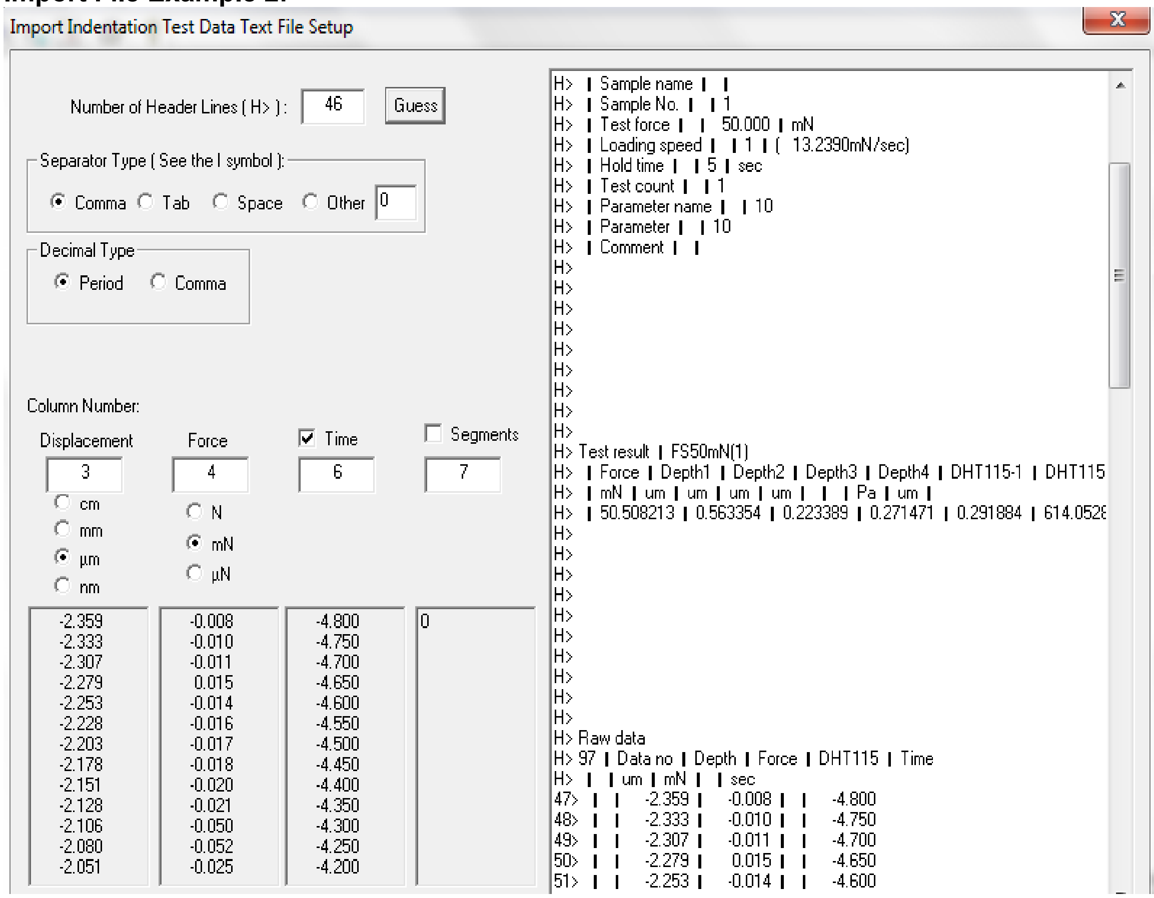
Data (.CSV)

This function saves the curve data as it is displayed on the Dureza software window with the curve corrections (Instrument Setup). The calculation for the elastic modulus hardness and other curve dimensions are also saved in a format that is easy to analysis with a spreadsheet program.

Import Example 1:

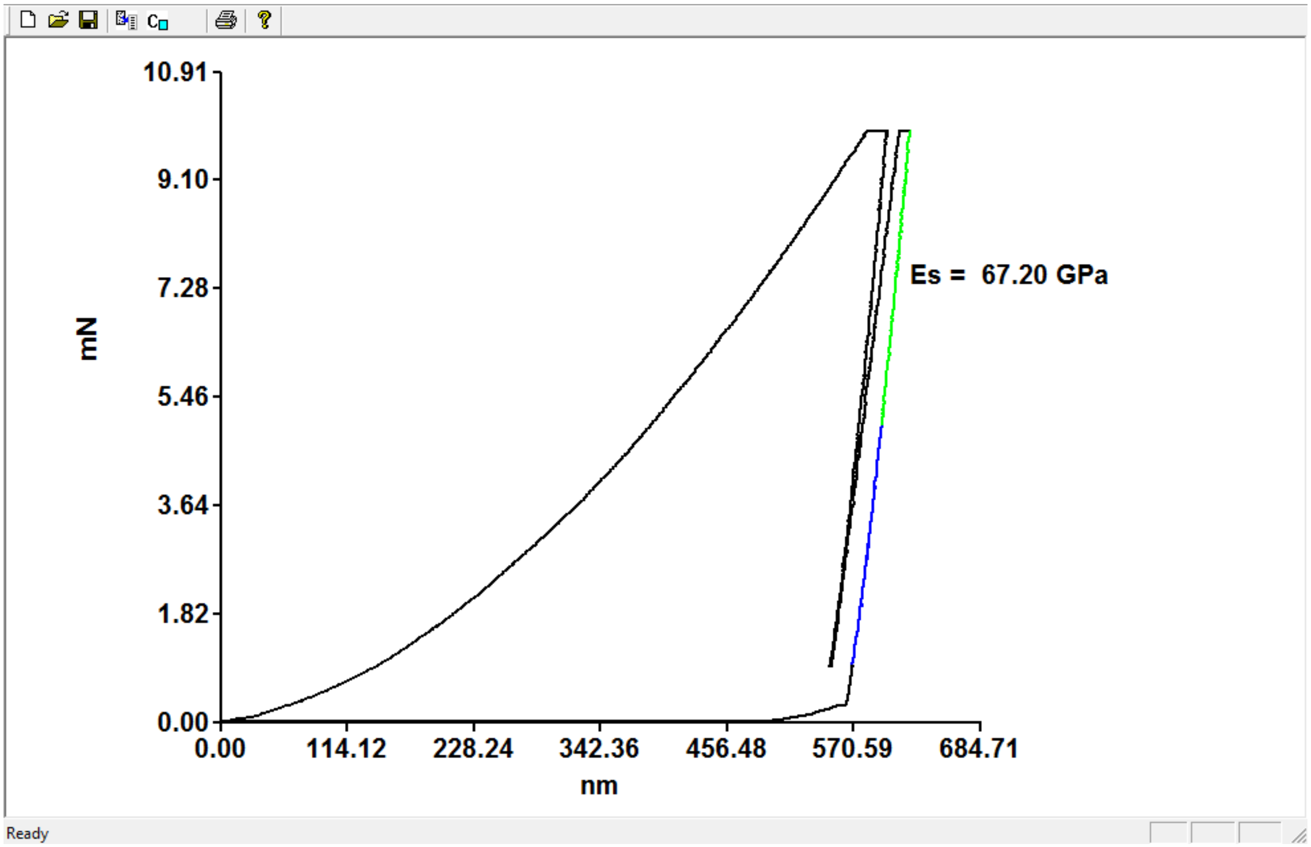


Import File Example 2:



Main Output Window:

Once a file is load here is what you will typically see. This is the Indent Grapher output window for an aluminum sample. It is where you will analyze and compare various indentation curves. You can import several curve files at the same time. The left and right click can be used to do calculations or change the graph view.



Saving Results:

Save
Save As
The Save and Save As will save just the file names that are open. They can be open again at a later date as a group of files.

Save As .DRZ
The DRZ file format also uses comma seperators. The .DRZ is the file format created by the IndentGrapher. The segment types are LOAD, UNLOAD, RELOAD, TOP_HOLD, BOTTOM_HOLD.

Format of a .DRZ

```
Depth(um),Force(mN),Time(s),Segment
1.000000e-003,5.500000e-002,0.300000,LOAD
4.000000e-003,1.380000e-001,0.350000,LOAD
1.000000e-002,2.210000e-001,0.400000,LOAD
1.600000e-002,3.320000e-001,0.450000,LOAD
2.300000e-002,4.980000e-001,0.500000,LOAD
3.000000e-002,6.910000e-001,0.550000,LOAD
3.800000e-002,9.130000e-001,0.600000,LOAD
4.300000e-002,1.134000e+000,0.650000,LOAD
```

```
4.900000e-002,1.328000e+000,0.700000,LOAD
5.600000e-002,1.549000e+000,0.750000,LOAD
6.100000e-002,1.799000e+000,0.800000,LOAD
6.700000e-002,2.020000e+000,0.850000,LOAD
7.100000e-002,2.242000e+000,0.900000,LOAD
7.500000e-002,2.463000e+000,0.950000,LOAD
8.200000e-002,2.685000e+000,1.000000,LOAD
8.700000e-002,2.879000e+000,1.050000,LOAD
9.100000e-002,3.100000e+000,1.100000,LOAD
9.300000e-002,3.350000e+000,1.150000,LOAD
9.600000e-002,3.543000e+000,1.200000,LOAD
1.040000e-001,3.765000e+000,1.250000,LOAD
1.110000e-001,4.014000e+000,1.300000,LOAD
1.160000e-001,4.235000e+000,1.350000,LOAD
1.210000e-001,4.457000e+000,1.400000,LOAD
1.250000e-001,4.679000e+000,1.450000,LOAD
1.310000e-001,4.872000e+000,1.500000,LOAD
1.350000e-001,5.122000e+000,1.550000,LOAD
```
.... etc...

Analysis Types:

Each of these functions makes an XY graph using all the indentation curve files. It can be used to compare the modulus and hardness versus load depth or curve number. The more curves you select with the Import or Open function the longer it will take to process all the data. The Dureza software calculates the modulus or hardness based on the current Instrument settings.

Analysis Graininess Functions:

The elastic modulus variation along the unload and reload curves are caused by the grain size, microstructure orientation compared to the indenter, dislocation pileup, or testing machine noise. First a power-law fits is done to a constant elastic modulus range of the unload curve. Then the difference from the fit to the entire lenght of the unload curve is calculated and graphed.

This is a figure of the indentation loading and unloading curve for an aluminum sample. The graph on the right shows the variation in depth from the power law fit along the unloading curve. The green part of the curve was used for the power law fitting data. The difference was then calculated along the entire length of the unloading curve as show in the graph.

Elastic Modulus Analysis:

Equations used to calculate the elastic modulus or Poisson's ration of either the sample or the indenter.

$$Load: P = \alpha(h - hf)^{m}$$

$$Machine\ Compliance\ Factor: h_j = h_i - Cf\ P_i$$

$$Slope(dP/dh): S = \alpha\, m(h - hf)^{(m\ \ 1)}$$

$$Sneddon's: hc = hmax_j - \varepsilon\,(Pmax/S)$$

$$Projected\ Area\ of\ Contact\ at\ the\ contact\ depth(hc): Ap = a_0 hc^2 + a_1 hc$$
$$Example: a_0 = 24.56\ for\ an\ ideal\ Berkovich\ \text{or}\ Vickers\ Indenter;\ a_1\ is\ for\ tip\ rounding$$

$$Reduced\ Elastic\ Modulus: E_R = (Shmax_j \sqrt{(\pi)})/(2\sqrt{(Ap)})$$
$$note: The\ S_{hmax}\ is\ the\ slope\ at\ the\ maximum\ depth\ for\ the\ indentation\ after\ correction\ Cf.$$

$$Elastic\ Modulus\ of\ Sample: Es = (1 - Vs^2)/((1/E_R) - ((1 - Vi^2)/Ei))$$

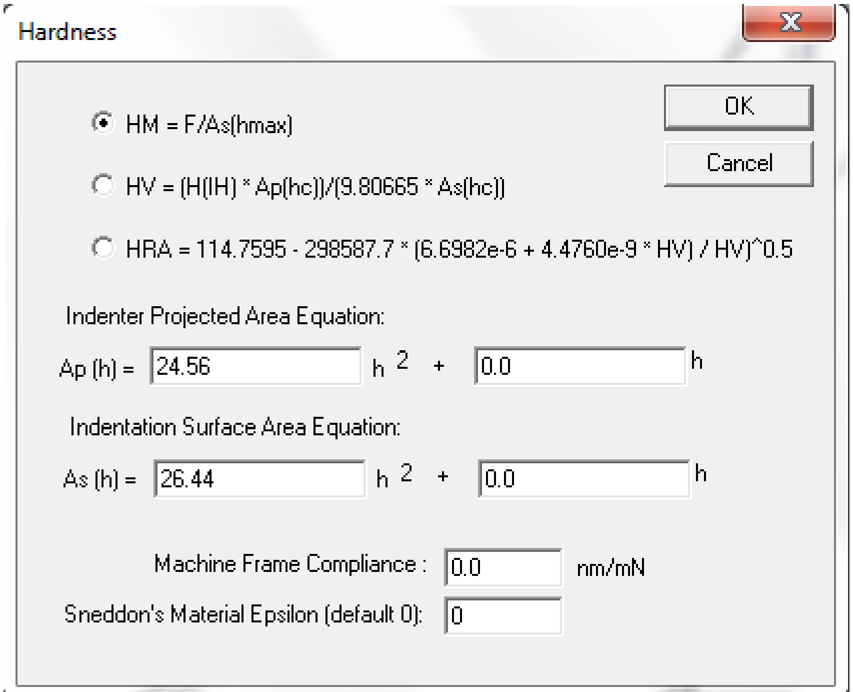
$$Poisson's\ Ratio\ of\ Sample: Vs = \sqrt{(1 - Es(1/E_R - (1 - Vi^2)/Ei))}$$

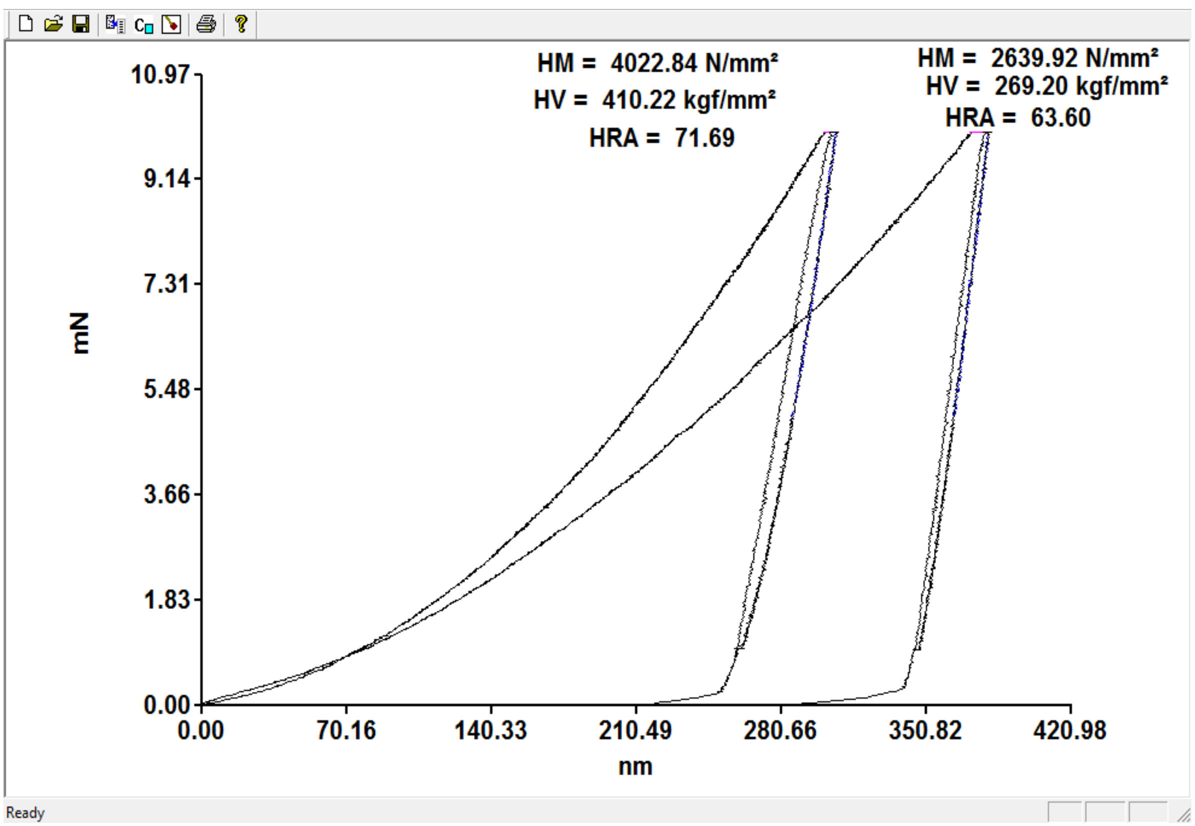
$$Elastic\ Modulus\ of\ Indenter: Ei = (1 - Vi^2)/((1/E_R) - ((1 - Vs^2)/Es))$$

$$Poisson's\ Ratio\ of\ Indenter: Vi = \sqrt{(1 - Ei(1/E_R - (1 - Vs^2)/Es))}$$

Hardness Analysis:

The hardness analysis function opens when you click on the top hold part of the load and unloading. Then select hardness type. The hardness analysis can be calibrated by changing the area function and machine frame compliance factors. After these values are set they should not be changed regular hardness analysis. Make sure you varify your hardness tester using a calibration block before each use. Document the results and plot them to see if the test instrument is out of calibration.





This figure shows the hardness results for ferritic and perlitic steel.

Setup:
These are the basic methods for instrumented indentation analysis as discussed in ISO 14577.

This dialog box is used to setup the Sneddon's epsilon which is usually 0.75 for most materials. The poisson's ratio is 0.17 for fused quartz and is usually 0.30 for metals.

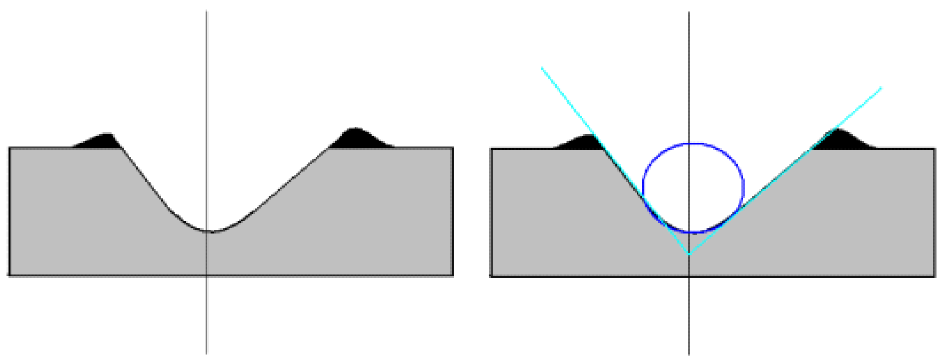
Machine Frame Compliance (Cf):

The compliance correction factor accounts for the machine elastic deformation of the machine during loading (Cf).

Force Accuracy:
The Instrument Force Accuracy is used to seperate the curve load, top_hold, unload, bottom_hold and reload sections. It is usually between 0.25 and 1 mN and depends on the quality of the testing machine and setup. The Instrument Displacement Accuracy is not used.

Area Function

Indenter tip rounding or damage must be accounted. The smaller the indentation size the greater the error caused by tip rounding. The figure below shows a light blue line for the ideal indenter shape and the circle shows the result of tip rounding. Usually only the first and second coefficients are needed to be considered (Ap = C1 h^2 + C2 h). For simplification the project area (Ap) function first coefficient (C1) is dependent on the indenter conical angle and the second coefficient (C2) the tip rounding.



Advanced Functions

Graininess E(h)
This shows a graph of the elastic modulus measured along the entire length of the unloading or reloading curve. The size of the sample section is set by using the maximum force percent and minimum force percent values. The initial force range is used to determine the hmax_ref used for all of the other calculations. The Pmax is the same for all of the section calculation for the elastic modulus. Multiple graininess curves can be graphed to together. The color of the graininess curve is identical to the load-unload curve unless its color is changed.

Equation for graininess maximum height: hmax_ref = (Pmax/alpha)^(1/m) + hf

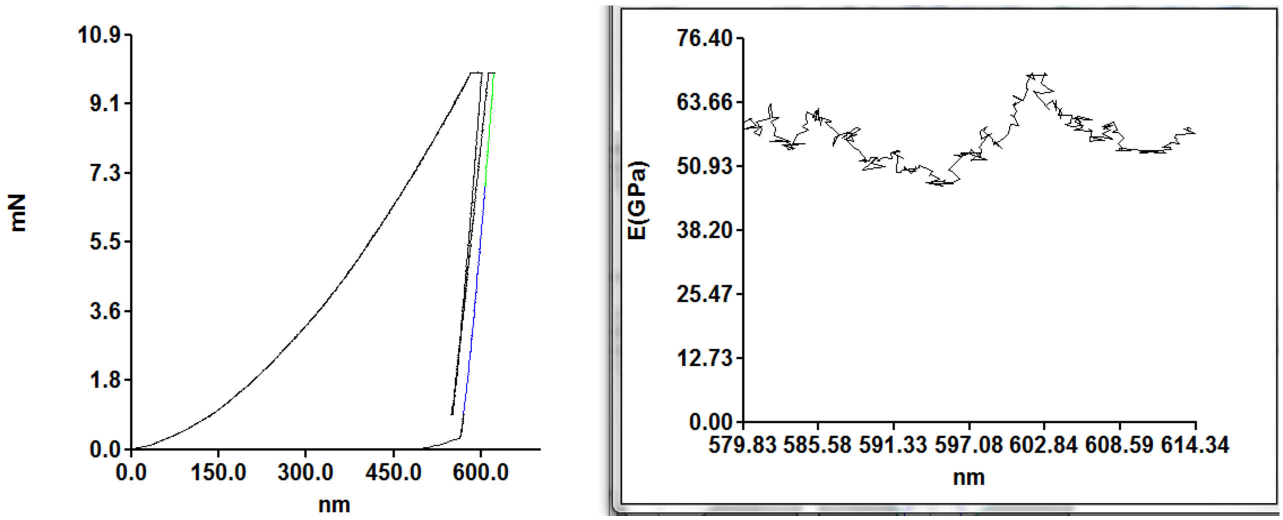


Figure of Graininess curve showing the change in elastic modulus with indentation depth for an aluminum 5050 sample.

Other Functions:
Loading Rate, Displacement Rate, and Power Law Equation. You can click on the loading curve to add the filename to the graph or calculated the displacement rate or loading rate.

Displacement Rate = (d(clicked point) - d(minimum for that segment)) / (t(clicked point) - t(mininum for that segment))

Force Rate = (f(clicked point) - f(minimum for that segment)) / (t(clicked point) - t(mininum for that segment))