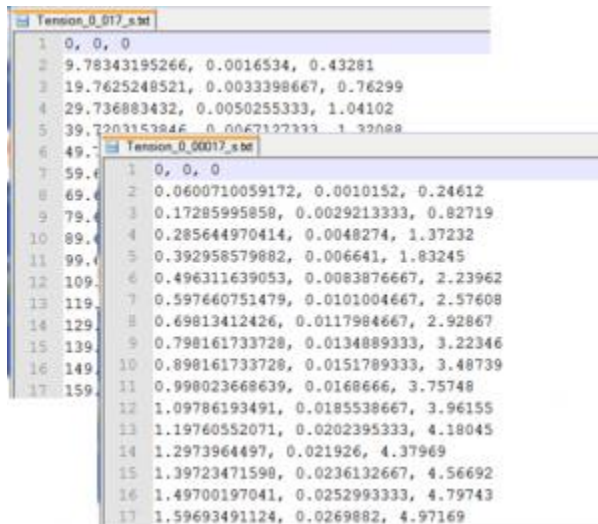


# Introduction to MCalibration®

In this tutorial you will learn to:

- Read a set of experimental data into MCalibration
- Use that data to calibrate a material model
- Use virtual experiments to examine the behavior of a calibrated material model
- Export the material model to a finite element input file

## Experimental Data



```
Tension_0_017_s.txt
1 0, 0, 0
2 9.78343195266, 0.0016534, 0.43281
3 19.7625248521, 0.0033398667, 0.76299
4 29.736883432, 0.0050255333, 1.04102
5 39.7203157846, 0.0067127333, 1.32088
6 49.7038071421, 0.0084000667, 1.60072
7 59.6872984296, 0.0100874, 1.88056
8 69.6707897171, 0.0117747333, 2.1604
9 79.6542810046, 0.0134620667, 2.44024
10 89.6377722921, 0.0151494, 2.72008
11 99.6212635796, 0.0168367333, 3.00002
12 109.6047548671, 0.0185240667, 3.27986
13 119.5882461546, 0.0202114, 3.5597
14 129.5717374421, 0.0218987333, 3.83954
15 139.5552287296, 0.0235860667, 4.11938
16 149.5387200171, 0.0252734, 4.39922
17 159.5222113046, 0.0269607333, 4.67906

Tension_0_00017_s.txt
1 0, 0, 0
2 0.0600710059172, 0.0010152, 0.24612
3 0.17285995858, 0.0029213333, 0.82719
4 0.285644970414, 0.0048274, 1.37232
5 0.392958579882, 0.006641, 1.83245
6 0.496311639053, 0.0083876667, 2.23962
7 0.597660751479, 0.0101004667, 2.57608
8 0.69813412426, 0.0117984667, 2.92867
9 0.798161733728, 0.0134889333, 3.22346
10 0.898161733728, 0.0151789333, 3.48739
11 0.998023668639, 0.0168666, 3.75748
12 1.09786193491, 0.0185538667, 3.96155
13 1.19760552071, 0.0202395333, 4.18045
14 1.2973964497, 0.021926, 4.37969
15 1.39723471598, 0.0236132667, 4.56692
16 1.49700197041, 0.0252993333, 4.79743
17 1.59693491124, 0.0269882, 4.97169
```

This simple example uses uniaxial tension data at two different strain rates. You may download the experimental data files here: [TensionData1](#) and [TensionData2](#). The figures to the right show parts of the data files using a text editor.

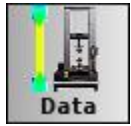
The following [page](#) contains more info about what experimental data MCalibration requires.

## MCalibration Main Window

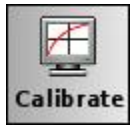
Before reading the experimental data let's examine the different parts of the main window. The main window has 4 different sections:



**Welcome:** This section can be used to open recently used calibration files (called mcal-files).



**Data:** This section is used to view and edit experimental data.



**Calibrate:** This section is used to calibrate material models, and to examine the response of a material model.

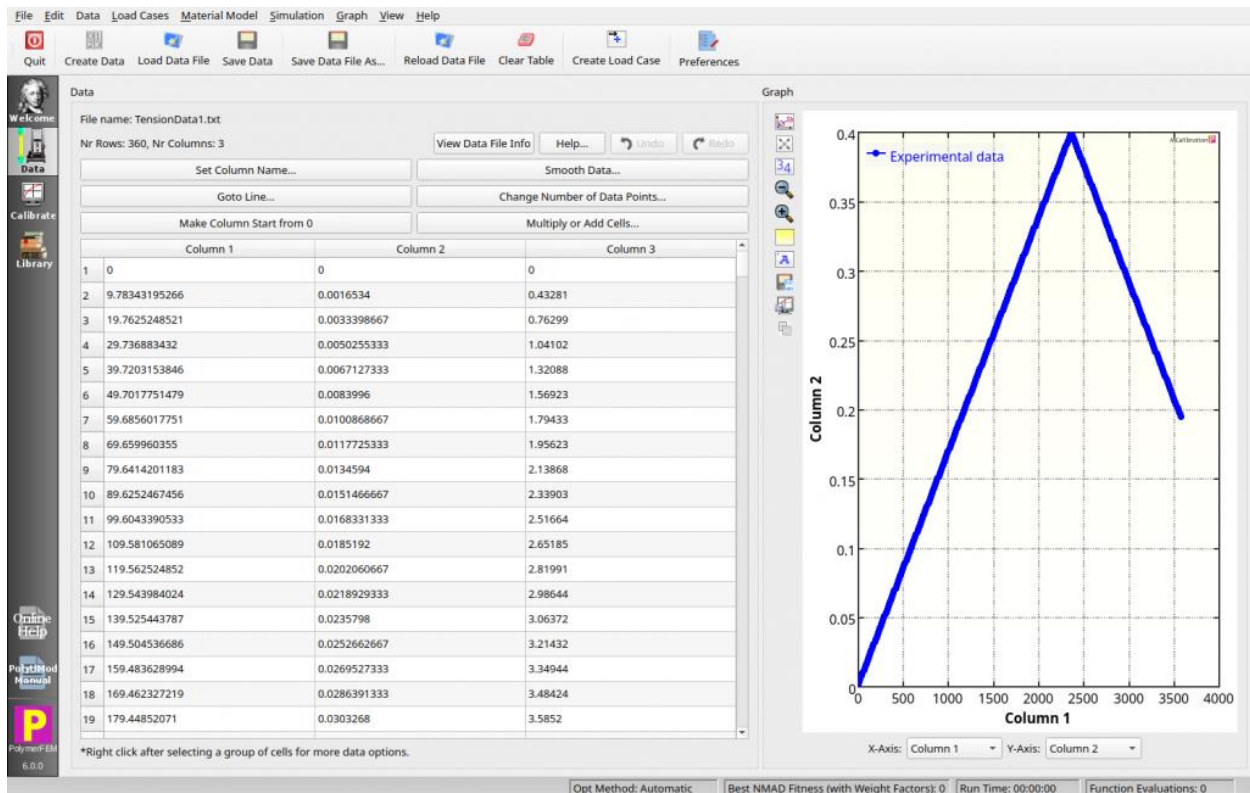


**Library:** Contains a user's collection of already calibrated models for different materials.

## Data Section

Switch to the Data section by clicking on the Data icon in the toolbar to the left.

Click on Load Data File to read in the first experimental data downloaded above (TensionData1).

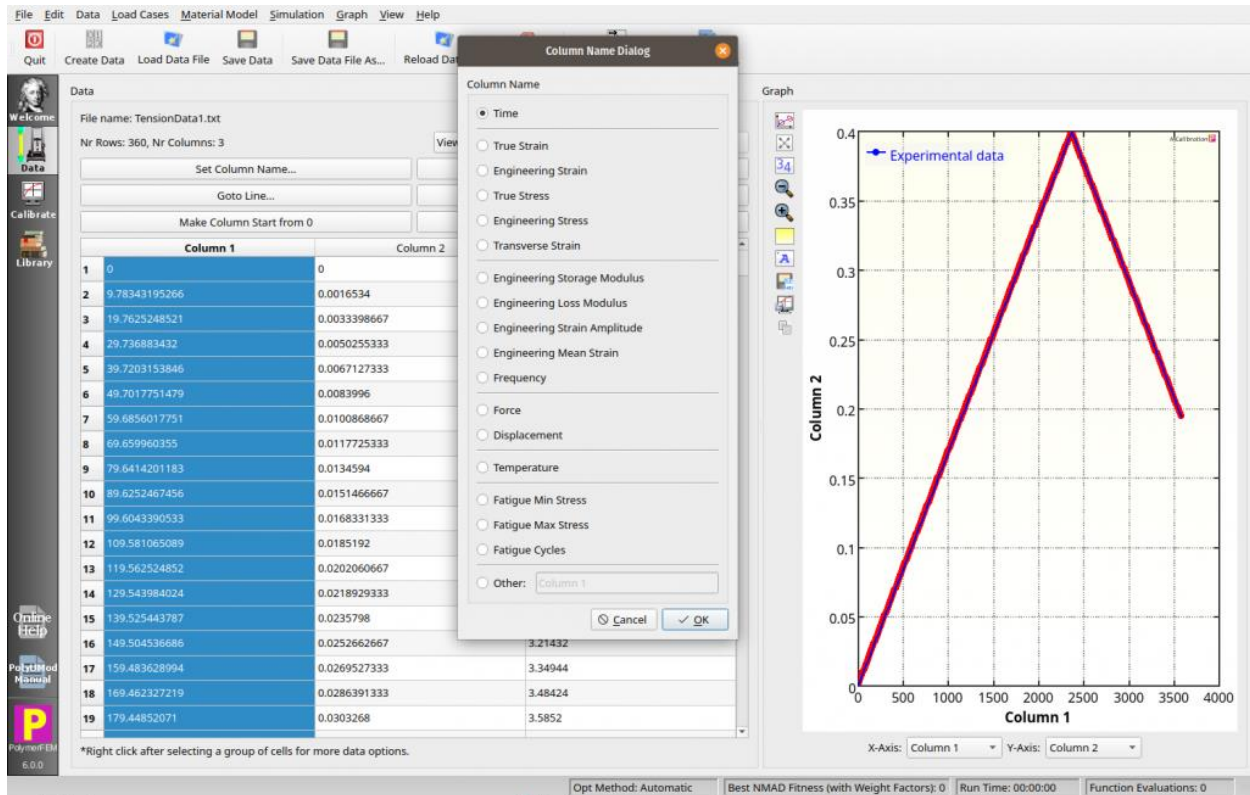


Next, we specify what the different columns of data contain.

1. Select Column 1 (or bring up a context menu by right-clicking in the column).
2. Then select Set Column Name.
3. Select Time and click OK.

This assigns column 1 as a time column.

Repeat these steps to assign column 2 as engineering strain, and column 3 as engineering stress.



Start creating a “load case” for the material model calibration by clicking on the Create Load Case button.

Note: A load case is the same as an experimental test that can be used for material model calibration.

Note: The Data Section contains many functions for making experimental data suitable for material model calibration.

File Edit Data Load Cases Material Model Simulation Graph View Help

Quit Create Data Load Data File Save Data Save Data File As... Reload Data File Clear Table **Create Load Case** Preferences

**Data**

File name: TensionData1.txt  
 Nr Rows: 360, Nr Columns: 3  
 View Data File Info Help... Undo Redo

Set Column Name... Smooth Data...  
 Goto Line... Change Number of Data Points...  
 Make Column Start from 0 Multiply or Add Cells...

	Time	Engineering Strain	Engineering Stress
1	0	0	0
2	9.78343195266	0.0016534	0.43281
3	19.7625248521	0.003398667	0.76299
4	29.736883432	0.0050255333	1.04102
5	39.7203153846	0.0067127333	1.32088
6	49.7017751479	0.0083996	1.56923
7	59.6856017751	0.0100868667	1.79433
8	69.659960355	0.0117725333	1.95623
9	79.6414201183	0.0134594	2.13868
10	89.6252467456	0.0151466667	2.33903
11	99.6043390533	0.0168331333	2.51664
12	109.581065089	0.0185192	2.65185
13	119.562524852	0.0202060667	2.81991
14	129.543984024	0.0218929333	2.98644
15	139.525443787	0.0235798	3.06372
16	149.504536686	0.0252662667	3.21432
17	159.483628994	0.0269527333	3.34944
18	169.462327219	0.0286391333	3.48424
19	179.44852071	0.0303268	3.5852

\*Right click after selecting a group of cells for more data options.

**Graph**

X-Axis: Time Y-Axis: Engineering St

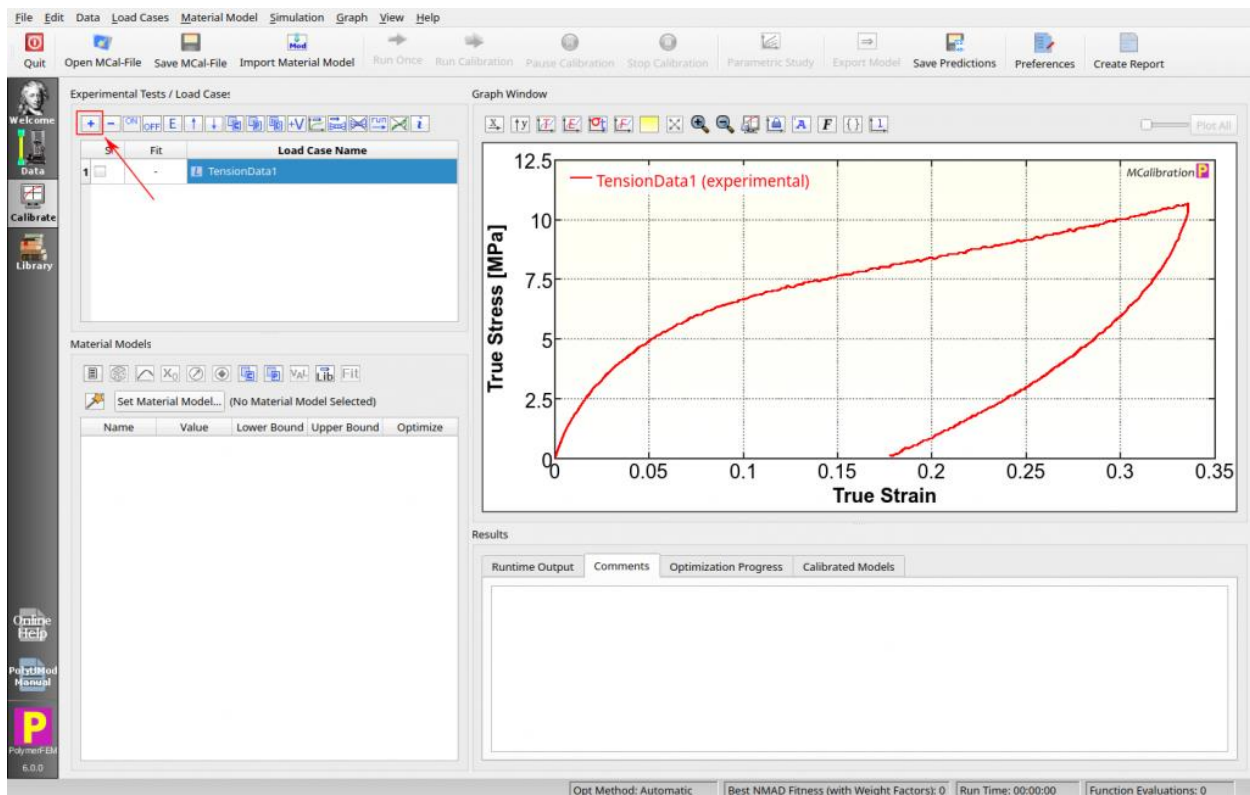
Opt Method: Automatic Best NMAD Fitness (with Weight Factors): 0 Run Time: 00:00:00 Function Evaluations: 0

## Calibrate Section

MCalibration switches to the Calibrate section when the save button is clicked in the load case dialog.

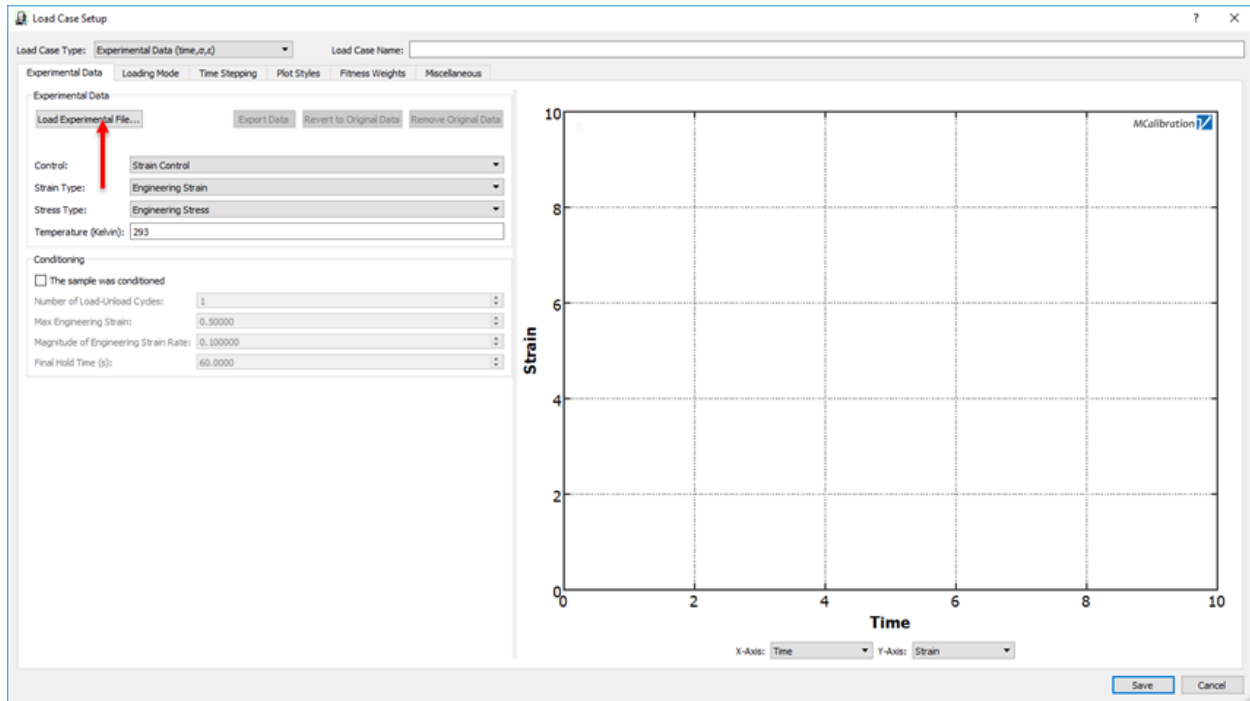
Before starting the calibration we need to read in the second experimental data file. To do this we can switch to the Data section and repeat the steps just performed. Instead, here we will illustrate another way.

- Click on the + button to add a Load Case.



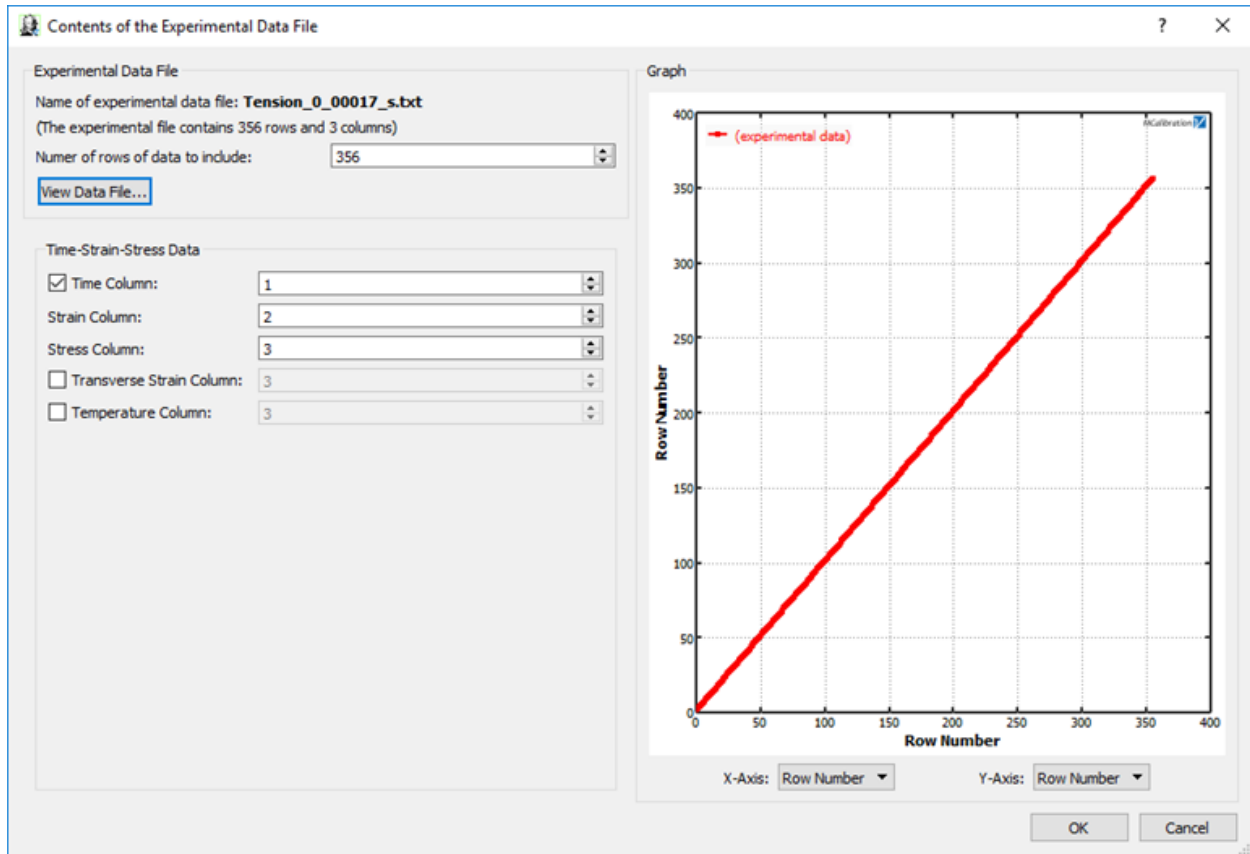
This brings up an empty Load Case dialog box.

- Click on the Load Experimental File... button.
- Select the TensionData2.txt file downloaded earlier. Then click OK.



This opens a dialog box that is used to specify the contents of the experimental data file

- Here time is in column 1, strain is in column 2, and stress is in column 3.
- Click the OK button.

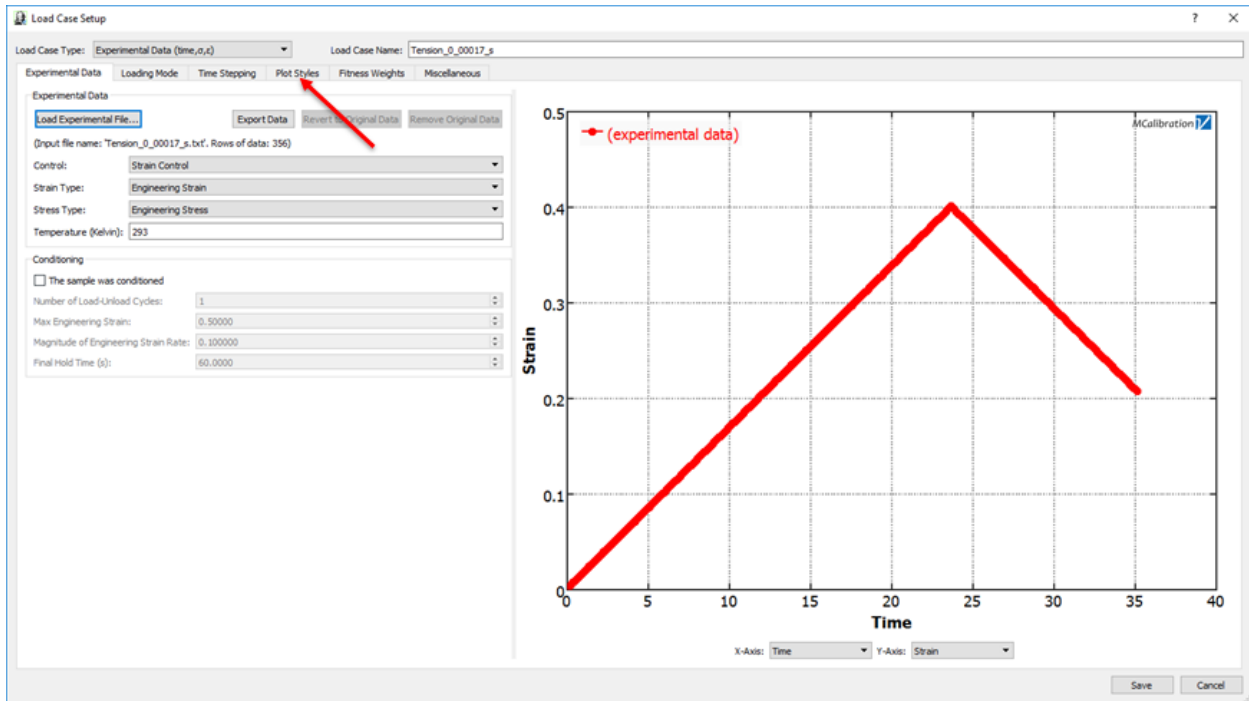


This loads the experimental data into the Load Case Setup dialog box.

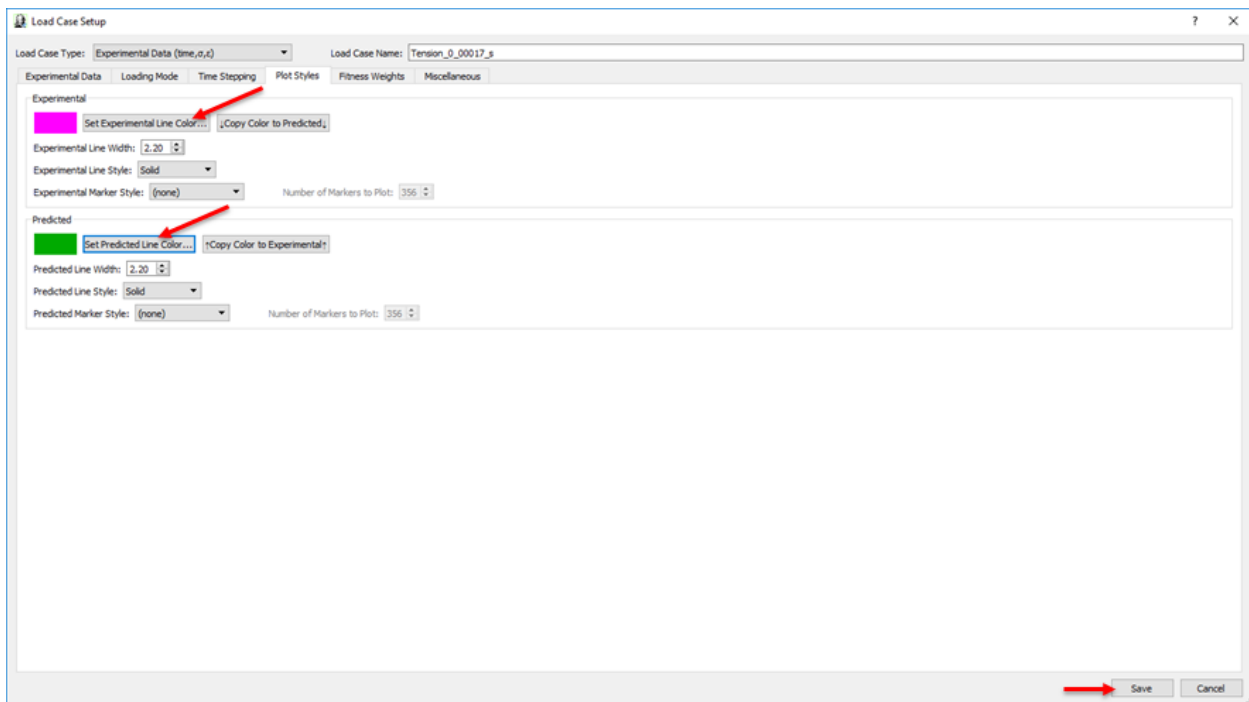
Most of the default settings are OK, but let's change the line colors of this load case.

Click on the Plot Styles tab.





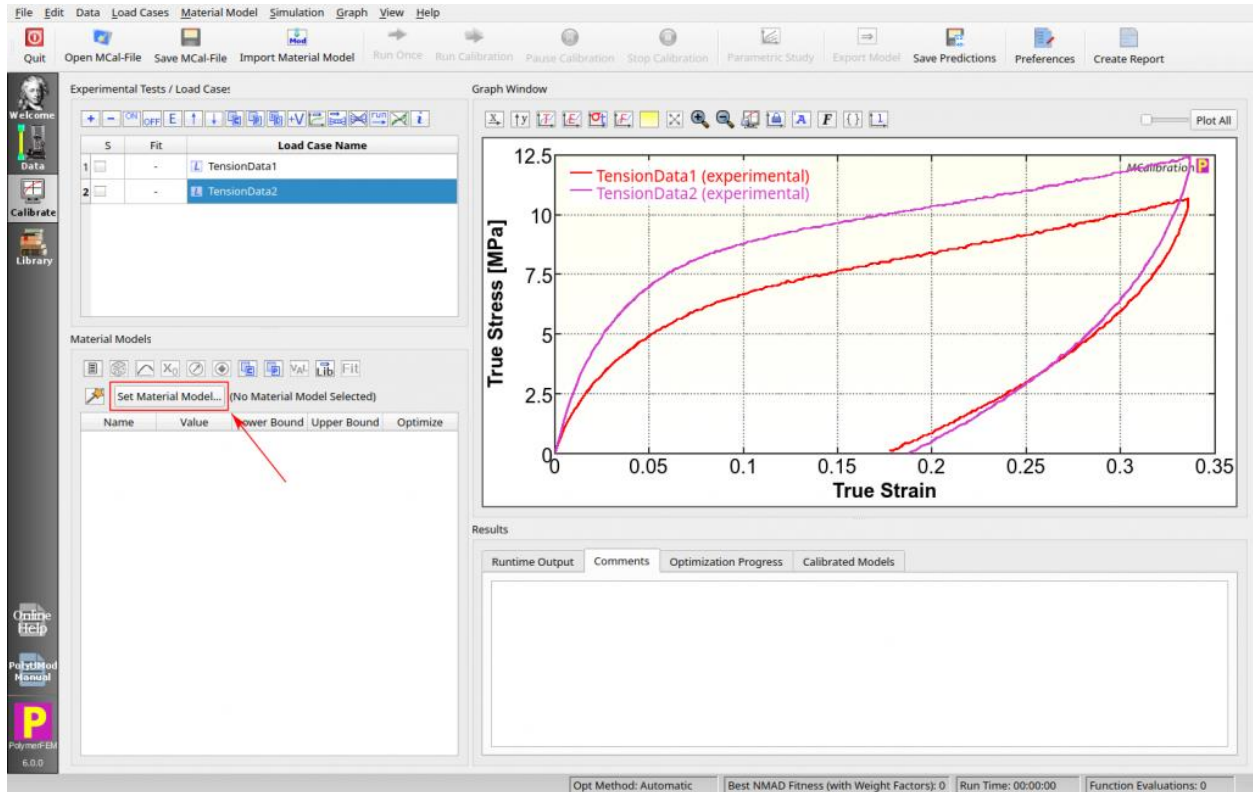
- Click on the Set Experimental Line Color... button.
- Click on the Set Predicted Line Color... button
- Click Save when done.



## Material Model

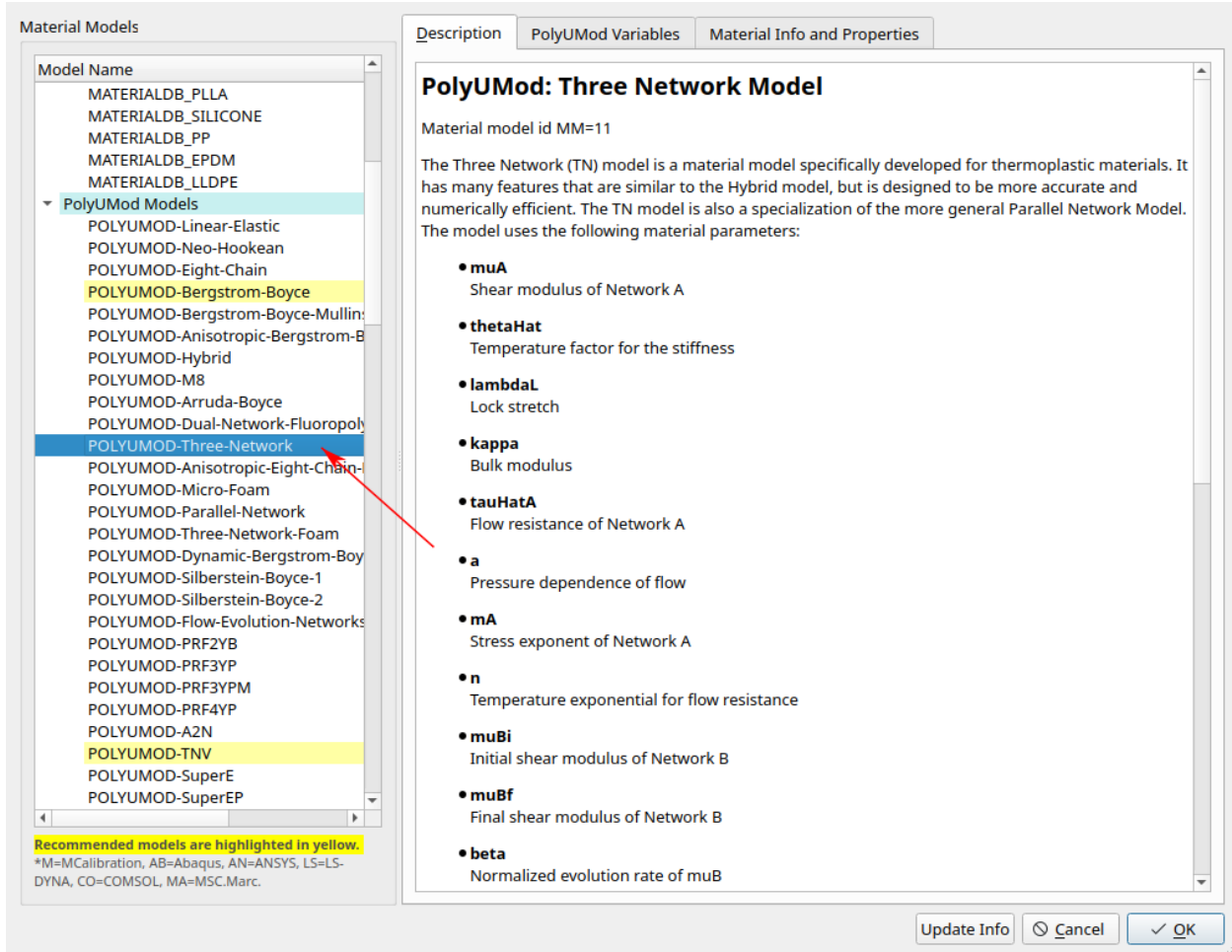
The next step is to select a suitable material model.

Click the Set Material Model... button.



The experimental data in this example is for a medium density polyethylene (MDPE), so the Three Network (TN) model from the PolyUMod library is a good choice.

- (Optional) Fill out your information in the Material Info and Properties tab on the right.
- Select the Three-Network Model item, then click OK.



MCalibration then selects an initial guess of the material parameters based on the available experimental data.

Click Run Once to calculate the predicted stress-strain response of the current material model.

File Edit Data Load Cases Material Model Simulation Graph View Help

Quit Open MCal-File Save MCal-File Import Material Model **Run Once** Run Calibration Pause Calibration Stop Calibration Parametric Study Export Model Save Predictions Preferences Create Report

Experimental Tests / Load Cases

S	Fit	Load Case Name
1	-	TensionData1
2	-	TensionData2

Graph Window

True Stress [MPa]

True Strain

— TensionData1 (experimental)  
— TensionData2 (experimental)

Results

Runtime Output Comments Optimization Progress Calibrated Models

Opt Method: Automatic Best NMAD Fitness (with Weight Factors): 0 Run Time: 00:00:00 Function Evaluations: 0

Material Models

Set Material Model... POLYUMOD-Three-Network

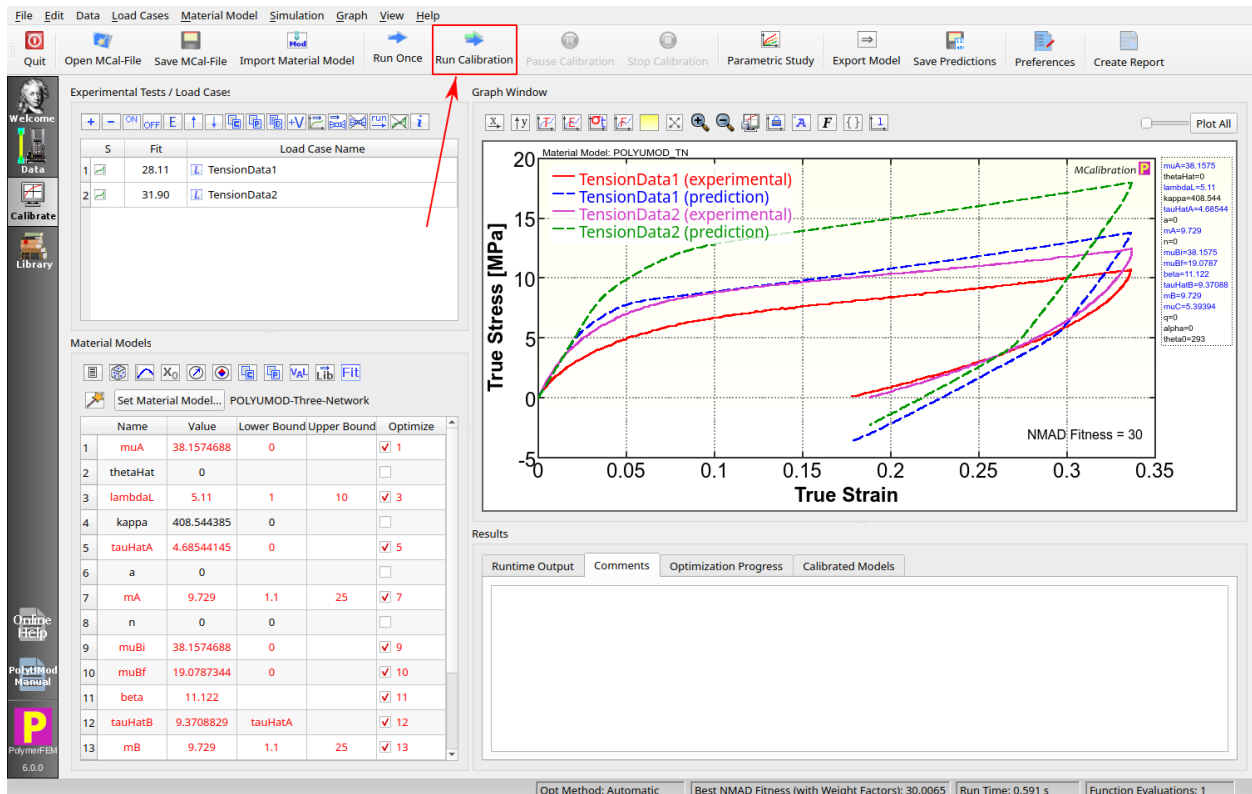
Name	Value	Lower Bound	Upper Bound	Optimize
1	muA	38.1574688	0	<input checked="" type="checkbox"/> 1
2	thetaHat	0		<input type="checkbox"/>
3	lambdaL	5.11	1 10	<input checked="" type="checkbox"/> 3
4	kappa	408.544385	0	<input type="checkbox"/>
5	tauHatA	4.68544145	0	<input checked="" type="checkbox"/> 5
6	a	0		<input type="checkbox"/>
7	mA	9.729	1.1 25	<input checked="" type="checkbox"/> 7
8	n	0	0	<input type="checkbox"/>
9	muB	38.1574688	0	<input checked="" type="checkbox"/> 9
10	muBF	19.0787344	0	<input checked="" type="checkbox"/> 10
11	beta	11.122		<input checked="" type="checkbox"/> 11
12	tauHatB	9.3708829	tauHatA	<input checked="" type="checkbox"/> 12
13	mB	9.729	1.1 25	<input checked="" type="checkbox"/> 13

# Preliminary Calibration

The predicted stress-strain curves are shown in here blue and green, and the experimental curves are shown in red and purple. Note that the material model has not been calibrated yet. The results shown here are just the predictions from the initial guess.

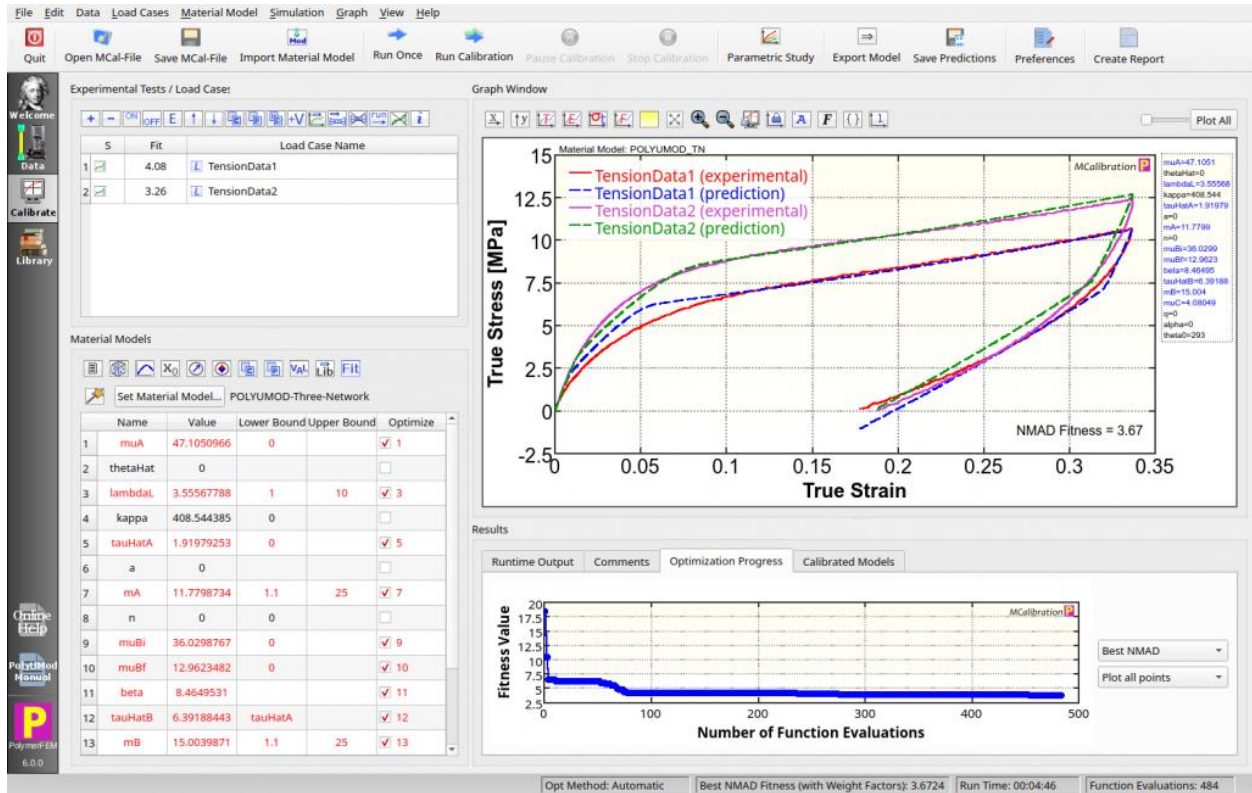
Each material parameter can either be fixed or part of the optimization. The Optimize column specifies the state of the parameters. All parameters with a non-zero positive value are included in the optimization. If two parameters are given the same optimization value then those two parameters are forced to have the same (unknown) value.

- Click Save File to save the current calibration file.
- Click Run Calibration to start optimizing the material parameters.



# Model Calibration

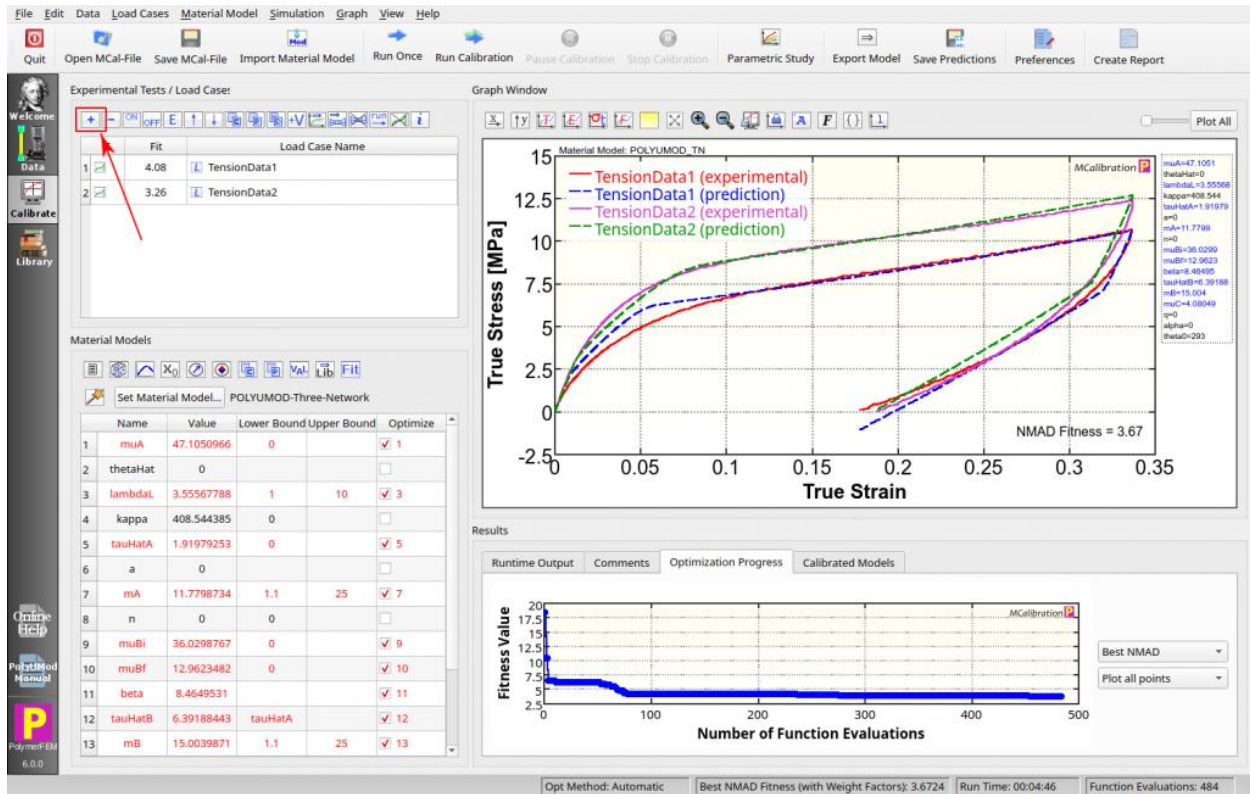
We manually stopped the calibration after a few minutes. At this point the error in the material model predictions (NMAD Fitness) is less than 3%.



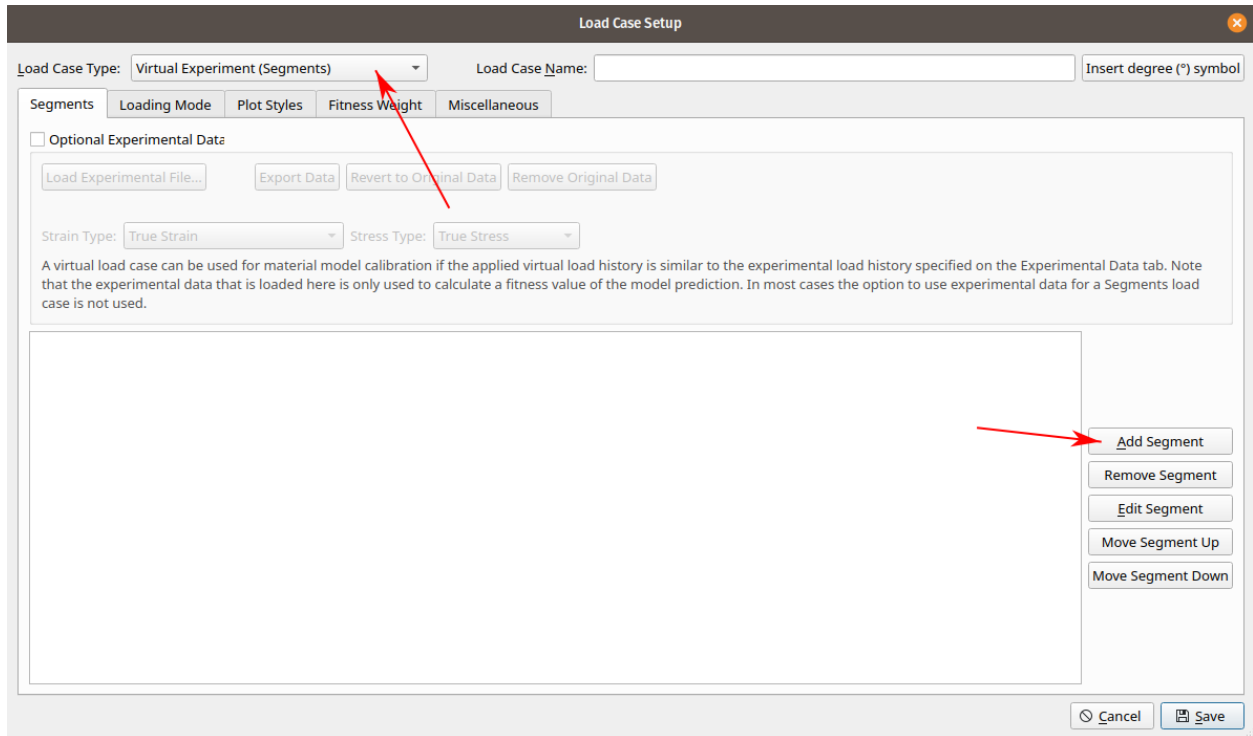
# Virtual Stress Relaxation

Sometimes it is useful to examine how a material model behaves under conditions that have not been experimentally tested. Here we will perform a virtual uniaxial compression experiment to an engineering strain of -0.1 followed by 60 seconds of relaxation.

- Click on the + button to setup the virtual experiment.

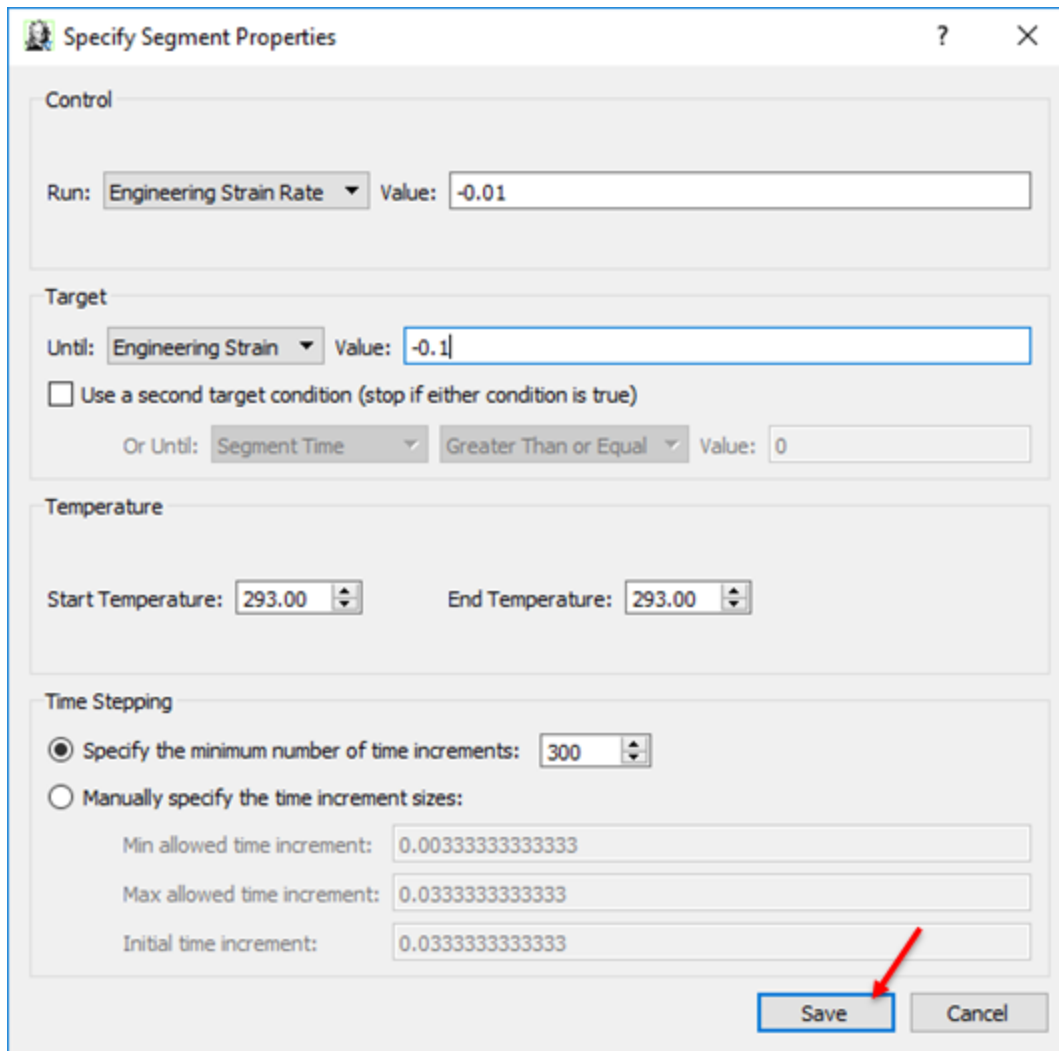


- Select Virtual Experiment (Segments) from the load case type drop down list.
- Click Add Segment.



- Specify the target strain rate and strain value. This specifies the stress relaxation pre-load.
- Then click the Save button.

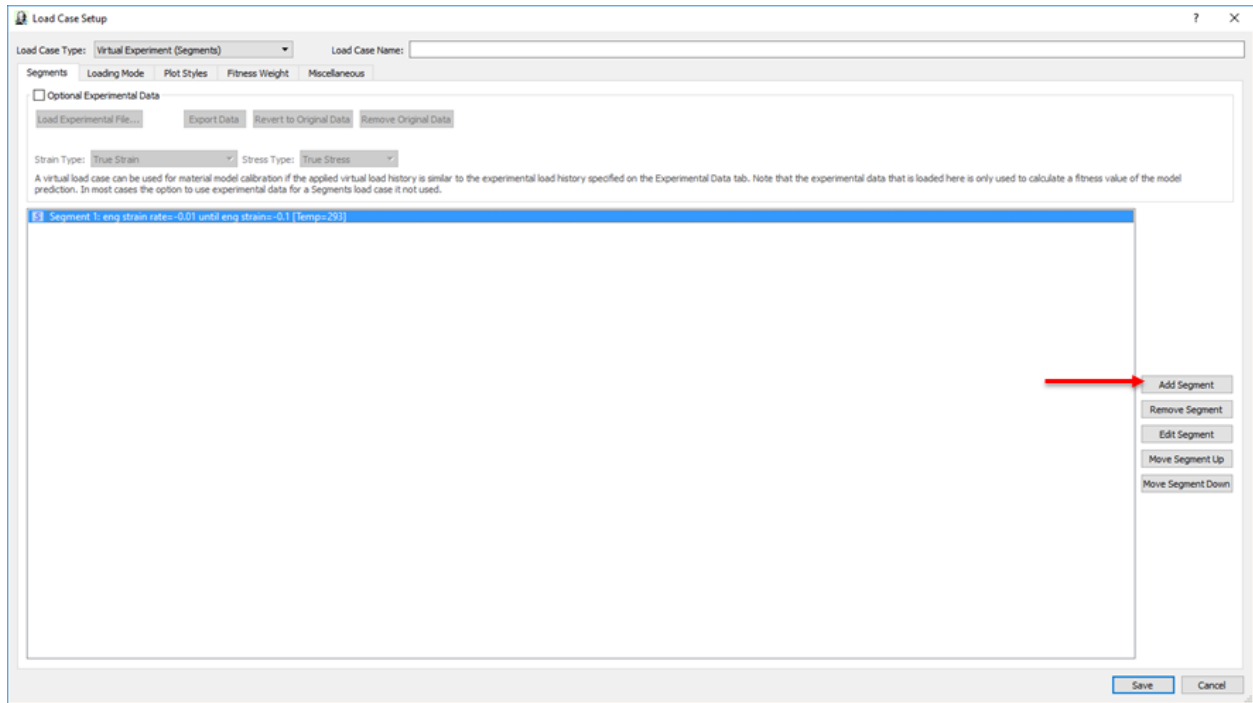




The image shows a software dialog box titled "Specify Segment Properties". It is divided into four main sections: Control, Target, Temperature, and Time Stepping. In the Control section, the "Run" dropdown is set to "Engineering Strain Rate" and the "Value" field contains "-0.01". In the Target section, the "Until" dropdown is set to "Engineering Strain" and the "Value" field contains "-0.1". There is an unchecked checkbox for "Use a second target condition (stop if either condition is true)". Below it, the "Or Until" dropdown is set to "Segment Time", the operator dropdown is set to "Greater Than or Equal", and the "Value" field contains "0". In the Temperature section, both "Start Temperature" and "End Temperature" are set to "293.00". In the Time Stepping section, the radio button for "Specify the minimum number of time increments:" is selected, and the value is "300". The other radio button, "Manually specify the time increment sizes:", is unselected. Below it, three input fields are present: "Min allowed time increment:" with value "0.00333333333333", "Max allowed time increment:" with value "0.03333333333333", and "Initial time increment:" with value "0.03333333333333". At the bottom right, there are "Save" and "Cancel" buttons. A red arrow points to the "Save" button.

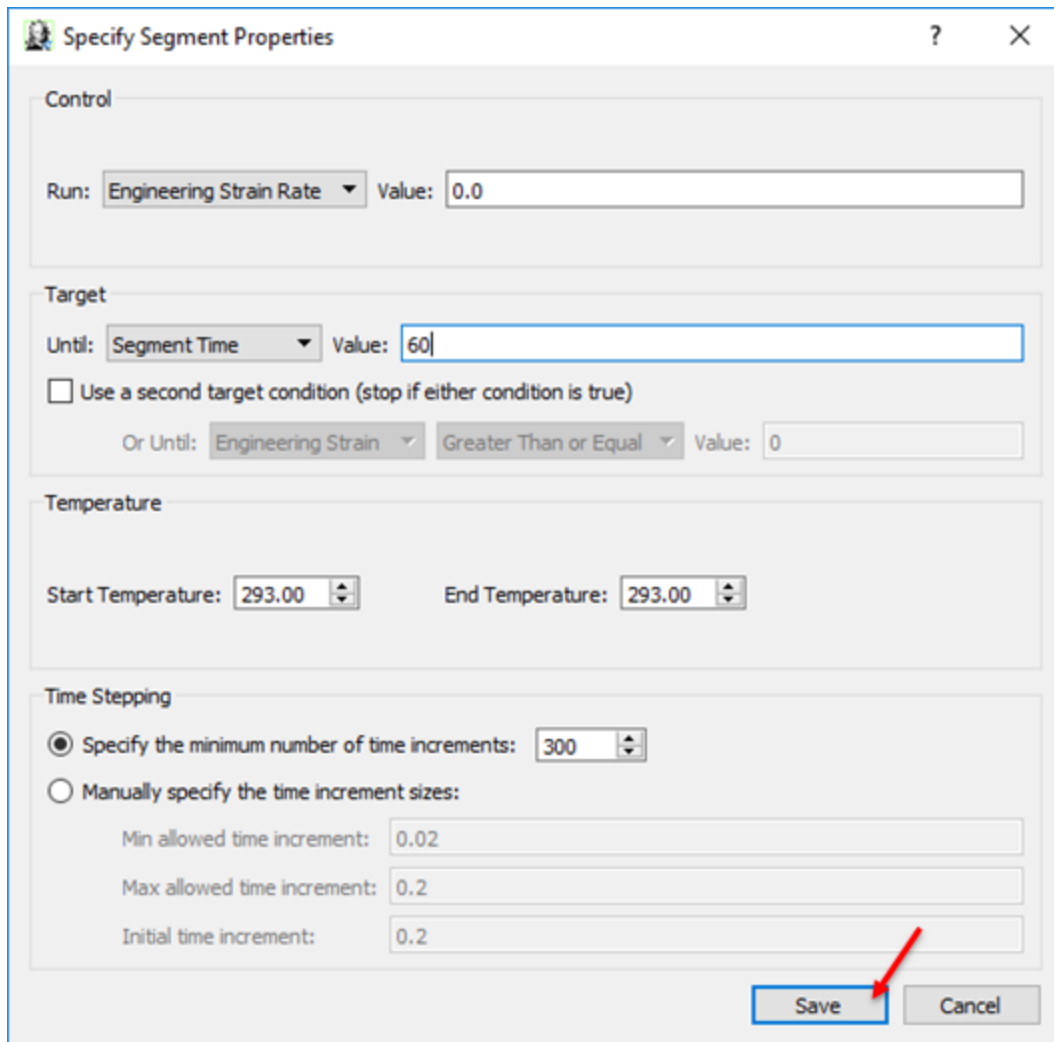
The load case dialog now contains the first loading segment of our virtual experiment. Next, we need to create the second stress relaxation segment.

- Click the Add Segment button.



The second loading segment has constant strain for 60 seconds.

- Click Save.



The image shows a dialog box titled "Specify Segment Properties" with a question mark and a close button in the top right corner. The dialog is divided into four sections: Control, Target, Temperature, and Time Stepping. In the Control section, the "Run:" dropdown is set to "Engineering Strain Rate" and the "Value:" field contains "0.0". In the Target section, the "Until:" dropdown is set to "Segment Time" and the "Value:" field contains "60". There is an unchecked checkbox labeled "Use a second target condition (stop if either condition is true)". Below it, the "Or Until:" dropdown is set to "Engineering Strain", the "Greater Than or Equal" dropdown is selected, and the "Value:" field contains "0". In the Temperature section, both "Start Temperature:" and "End Temperature:" are set to "293.00". In the Time Stepping section, the "Specify the minimum number of time increments:" radio button is selected, and the value "300" is entered in the adjacent field. The "Manually specify the time increment sizes:" radio button is unselected. Below it, three fields are present: "Min allowed time increment:" with "0.02", "Max allowed time increment:" with "0.2", and "Initial time increment:" with "0.2". At the bottom right, there are "Save" and "Cancel" buttons. A red arrow points to the "Save" button.

Back in the main window click the Run Once button to evaluate the new load virtual experiment.

We see that the predicted stress relaxes about 30% in 60 seconds.

The next step is to export the calibrated model to a FE program.

- Click the Export Model button.

File Edit Data Load Cases Material Model Simulation Graph View Help

Quit Open MCal-File Save MCal-File Import Material Model **Run Once** Run Calibration Pause Calibration Stop Calibration Parametric Study **Export Model** Save Predictions Preferences Create Report

Experimental Tests / Load Cases:

S	Fit	Load Case Name
1	4.00	TensionData1
2	3.37	TensionData2
3	-	LC 2: Virtual Experiment

Material Models

Set Material Model... POLYUMOD-Three-Network

Name	Value	Lower Bound	Upper Bound	Optimize
1	muA	47.1050966	0	<input checked="" type="checkbox"/> 1
2	thetaHat	0		<input type="checkbox"/>
3	lambdaL	3.55567788	1 10	<input checked="" type="checkbox"/> 3
4	kappa	408.544385	0	<input type="checkbox"/>
5	tauHatA	1.91979253	0	<input checked="" type="checkbox"/> 5
6	a	0		<input type="checkbox"/>
7	mA	11.7798734	1.1 25	<input checked="" type="checkbox"/> 7
8	n	0	0	<input type="checkbox"/>
9	muBi	36.0298767	0	<input checked="" type="checkbox"/> 9
10	muBF	12.9623482	0	<input checked="" type="checkbox"/> 10
11	beta	8.4649531		<input checked="" type="checkbox"/> 11
12	tauHatB	6.39188443	tauHatA	<input checked="" type="checkbox"/> 12
13	mB	15.0039871	1.1 25	<input checked="" type="checkbox"/> 13

Graph Window

Material Model: POLYUMOD\_TN

- TensionData1 (experimental)  
 - TensionData1 (prediction)  
 - TensionData2 (experimental)  
 - TensionData2 (prediction)  
 - LC 2: Virtual Experiment (prediction)

MCalibration

muA=47.1051  
 thetaHat=0  
 lambdaL=3.55568  
 kappa=408.544  
 tauHatA=1.91979  
 a=0  
 mA=11.7799  
 n=0  
 muBi=36.0299  
 muBF=12.9623  
 beta=8.46495  
 tauHatB=6.39188  
 mB=15.004  
 muC=4.08049  
 q=0  
 alpha=0  
 betaL=293

NMAD Fitness = 3e+09

Results

Runtime Output Comments Optimization Progress Calibrated Models

Best NMAD  
Plot all points

Opt. Method: Automatic | Best NMAD Fitness (with Weight Factors): 3.68342 | Run Time: 0.904 s | Function Evaluations: 1

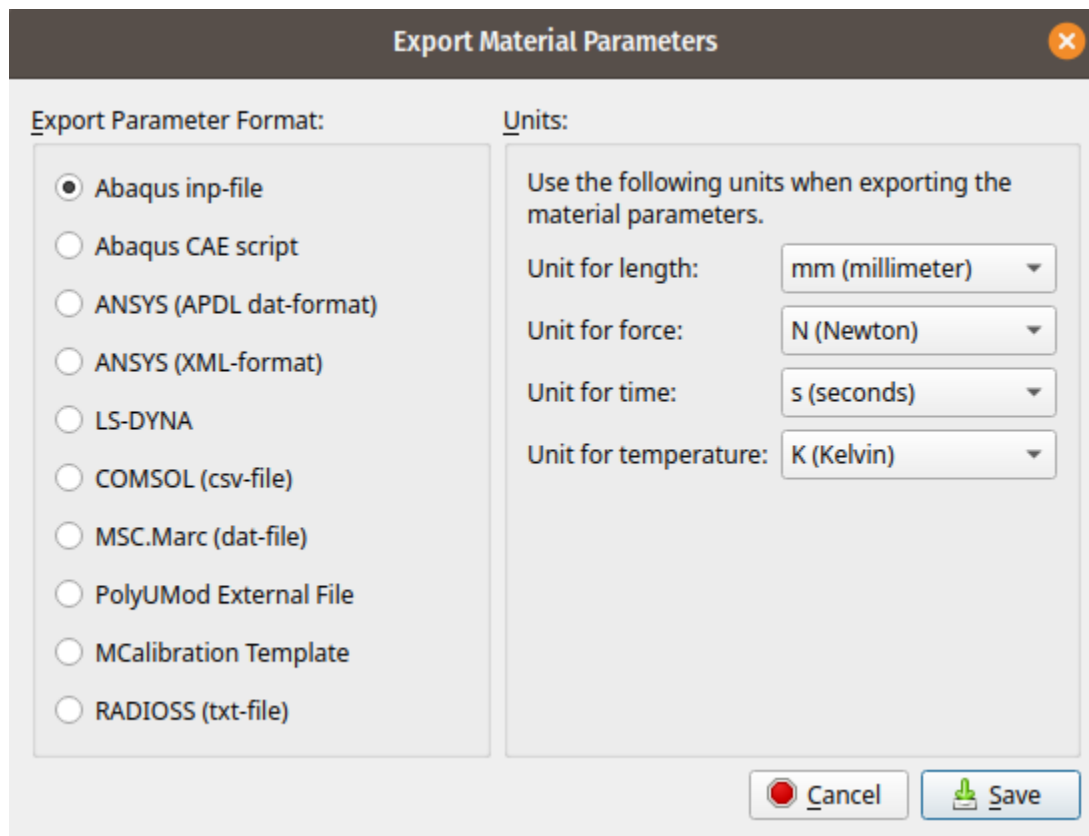
## Export Material Model

To export the material model to Abaqus/CAE select Abaqus CAE script or Abaqus inp-file, and click Save.

To export the material model to ANSYS select ANSYS (APDL or XML format), and click Save.

The material model can also be exported to MSC.Marc, LS-DYNA, Radioss, and COMSOL formats.

You may modify the saved units system from this dialog.



The dialog box is titled "Export Material Parameters" and features a close button (X) in the top right corner. It is divided into two main sections: "Export Parameter Format:" and "Units:".

**Export Parameter Format:** This section contains a list of radio buttons for selecting the export format:

- Abaqus inp-file
- Abaqus CAE script
- ANSYS (APDL dat-format)
- ANSYS (XML-format)
- LS-DYNA
- COMSOL (csv-file)
- MSC.Marc (dat-file)
- PolyUMod External File
- MCalibration Template
- RADIOSS (txt-file)

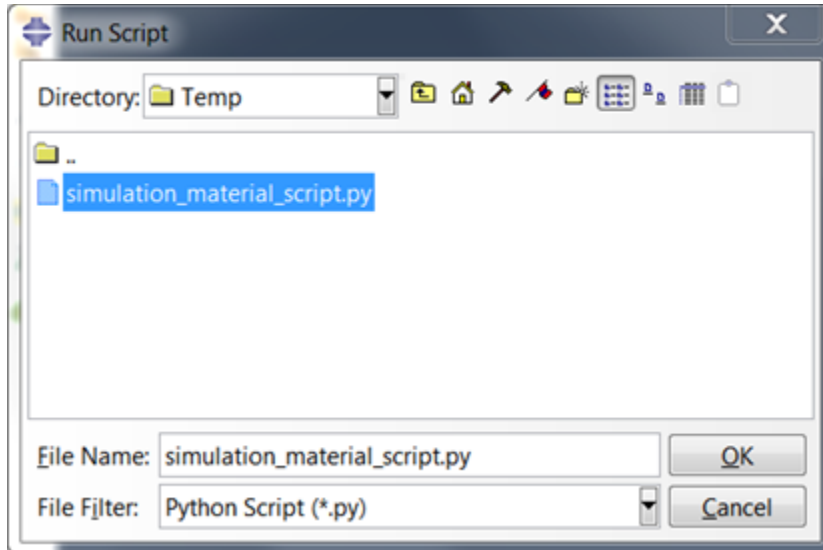
**Units:** This section is titled "Use the following units when exporting the material parameters." and contains four dropdown menus:

- Unit for length: mm (millimeter)
- Unit for force: N (Newton)
- Unit for time: s (seconds)
- Unit for temperature: K (Kelvin)

At the bottom right of the dialog, there are two buttons: "Cancel" (with a red stop icon) and "Save" (with a green floppy disk icon).

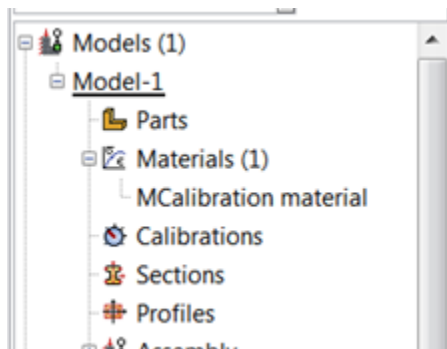
## Import Model Into Abaqus/CAE

In CAE select Run Script from the File Menu, then select the script file that was created by MCalibration.



The model tree then contains the calibrated material model.

For more examples, see also Validating the Installation (PolyUMod for Abaqus)

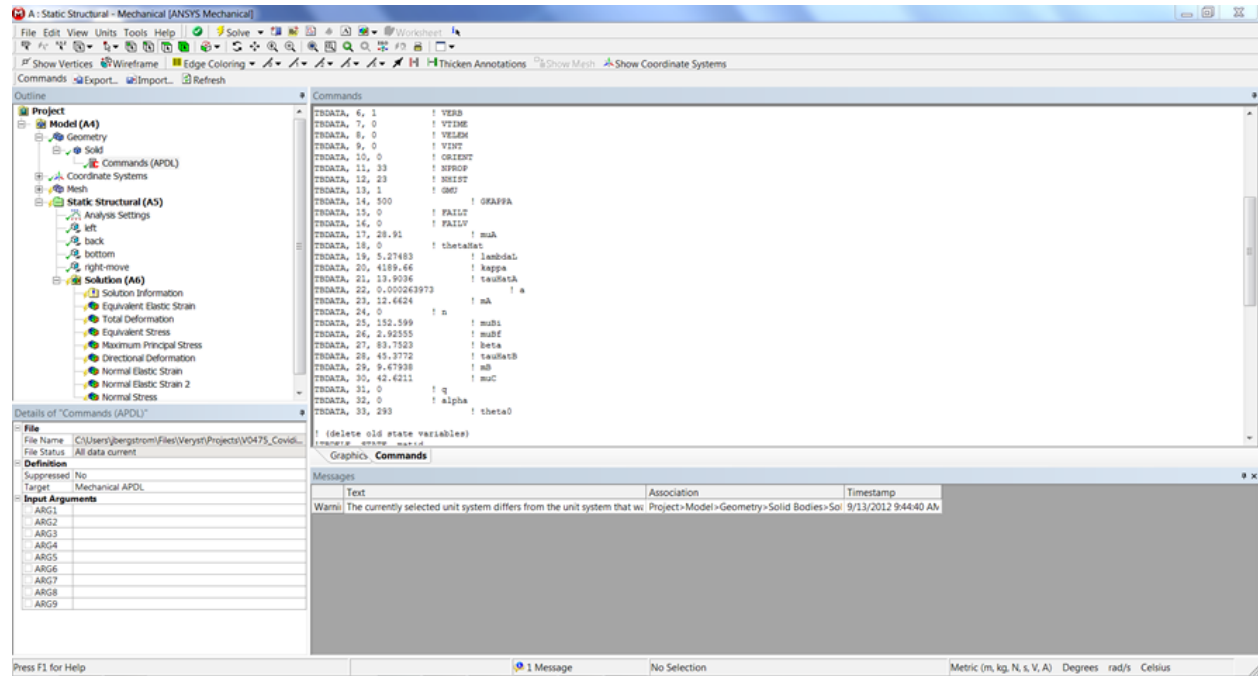


## Import the Model Into ANSYS WB

Read the .dat file exported from MCalibration into ANSYS Mechanical as a command under Geometry → Solid or read the .xml file into Engineering Data.

Make sure non-linear geometries are enabled in Mechanical.

See also Using PolyUMod with ANSYS Workbench.



## MCalibration File Format

MCalibration saves the simulation information in a file with the extension mcal.

- The mcal-file is a XML file that can be edited using a text editor.
- The file contains all experimental data and information about the different load cases and material models.
- Since the mcal-file contains the experimental data, the file can be moved to a new directory and still work.
- The experimental data that is stored in the mcal-file includes both the original data and the current version of the data (if the data has been modified in the Data tab).
- The original and modified experimental data sets can be exported to separate data files if needed.

```

...Mod/trunk/Case_Studies/MCalibration_Introductio
File Edit View Bookmarks Tools Settings Help
New Open Save Save As Close Undo Redo Quit
1 <?xml version="1.0" encoding="UTF-8"?>
2 <MCalibration>
3   <Created>File created by MCalibration on Sat Jan 23 08:31:35 2016</Created>
4   <Version>4.0.0</Version>
5
6   <Graph>
7     <graphColorTop>ffffff</graphColorTop>
8     <graphColorBot>ffffff</graphColorBot>
9     <axesNumbersFont>Calibri,12,-1,5,50,0,0,0,0</axesNumbersFont>
10    <axesNumbersFontColor>ff000000</axesNumbersFontColor>
11    <axesLabelsFont>Calibri,14,-1,5,75,0,0,0,0</axesLabelsFont>
12    <axesLabelsFontColor>ff000000</axesLabelsFontColor>
13    <legendFont>Calibri,10,-1,5,50,0,0,0,0</legendFont>
14    <legendColor>64f0f0f0</legendColor>
15    <legendPos>0</legendPos>
16    <legendRect>0.02, 0.02</legendRect>
17    <legendShown>true</legendShown>
18    <fitLabelFont>Calibri,10,-1,5,50,0,0,0,0</fitLabelFont>
19    <fitLabelFontColor>ff000000</fitLabelFontColor>
20    <fileNameLabelFont>Calibri,9,-1,5,50,0,0,0,0</fileNameLabelFont>
21    <fileNameLabelFontColor>ff828282</fileNameLabelFontColor>
22    <matModelLabelFont>Calibri,10,-1,5,50,0,0,0,0</matModelLabelFont>
23    <matModelLabelFontColor>ff000000</matModelLabelFontColor>
24    <matModelParamsFont>Calibri,7,-1,5,50,0,0,0,0</matModelParamsFont>
25    <matModelParamsFontColor>ff000000</matModelParamsFontColor>
26    <optAxesNumbersFont>Calibri,9,-1,5,50,0,0,0,0</optAxesNumbersFont>
27    <optAxesNumbersFontColor>ff000000</optAxesNumbersFontColor>
28    <optAxesLabelsFont>Calibri,10,-1,5,75,0,0,0,0</optAxesLabelsFont>
29    <optAxesLabelsFontColor>ff000000</optAxesLabelsFontColor>
30    <optLegendFont>Calibri,8,-1,5,50,0,0,0,0</optLegendFont>
31    <optLegendFontColor>64f0f0f0</optLegendFontColor>
32    <saveImgSizeX>1200</saveImgSizeX>
33    <saveImgSizeY>900</saveImgSizeY>
34    <saveImgResolution>150</saveImgResolution>
35    <xAxisQuantity>True Strain</xAxisQuantity>
36    <yAxisQuantity>True Stress [MPa]</yAxisQuantity>
37  </Graph>
38
39  <LoadCase type="experimental_data">
40    <name>Tension 0_017 s</name>
41    <fileName>Tension_0_017 s.txt</fileName>
42    <exp_orig_time>0, 9.783431952660001, 19.7625248521, 29.736883432, 39.7203153846
43    89.62524674559999,
44    99.6043390533, 109.581065089, 119.562524852, 129.543984024, 139.525443787, 14
45    199.404339053, 209.385798817, 219.36725858, 229.348717751, 239.323076923, 249
46    299.209072781, 309.190532544, 319.16725858, 329.148717751, 339.127810651, 349
47    399.014201183, 408.990927219, 418.971992308, 428.951084615, 438.934911243, 44
48    498.81183432, 508.793294083, 518.777120118, 528.753846154, 538.735305917, 548
49    598.616568047, 608.600394675, 618.574753254, 628.556213018, 638.537672781, 64
50    608.418024011, 708.200077011, 718.270402007, 728.262213600, 738.247466600001
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## MCalibration Summary

- MCalibration is an easy-to-use tool that can calibrate many different material models.
- One of the most powerful features of MCalibration is that it can use almost any combination of experimental data, e.g. tension, compression, shear, biaxial, triaxial, stress relaxation, creep, DMA, Poisson's ratio, etc.
- MCalibration can also use direct finite element simulations of more complicated experimental tests to calibrate a material model.