# 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**

| 1 | 0, 0, | . 0   |                                       |
|---|-------|-------|---------------------------------------|
| 2 | 9.78  | 34319 | 5266, 0.0016534, 0.43281              |
| 2 | 19.7  | 62524 | 18521, 0.0033398667, 0.76299          |
| 4 | 29.7  | 36883 | 432, 0.0050255333, 1.04102            |
| 5 | 39.7  | 20314 | 3846 0 0067127333 1 32088             |
| 6 | 49.1  | E Ter | tsion_0_00017_s bt                    |
| 1 | 59.6  | 1     | 0, 0, 0                               |
| 8 | 69.0  | 2     | 0.0600710059172, 0.0010152, 0.24612   |
| 9 | 79.4  | .3    | 0.17285995858, 0.0029213333, 0.82719  |
|   | 89.4  | 14    | 0.285644970414, 0.0048274, 1.37232    |
| 1 | 99.4  | 5     | 0.392958579882, 0.006641, 1.83245     |
| 2 | 109.  | 6     | 0.496311639053, 0.0083876667, 2.23962 |
| 3 | 119.  | 17    | 0.597660751479, 0.0101004667, 2.57608 |
| 4 | 129   | 1     | 0.69813412426, 0.0117984667, 2.92867  |
| 5 | 139.  | . 9   | 0.798161733728, 0.0134889333, 3.22346 |
| 6 | 149.  | 10    | 0.898161733728, 0.0151789333, 3.48739 |
| 7 | 159.  | 11    | 0.998023668639, 0.0168666, 3.75748    |
|   | 1000  | 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  |
|   | - 1   |       | 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: <u>TensionData1</u> and <u>TensionData2</u>. 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** 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).

|      | e Data Load Data File Save Data         | Save Data File As R         | teload Data File             | Clear Table           | Create Load Case | Preferences |          |      |            |        |      |               |                                       |      |          |     |
|------|---|-----------------------------|------------------------------|-----------------------|------------------|-------------|----------|------|------------|--------|------|---------------|---------------------------------------|------|----------|-----|
| Data |   |                             |                              |                       |                  |             | Graph    |      |            |        |      |               |                                       |      |          |     |
| File | e name: TensionData1.txt                |                             |                              |                       |                  |             | 123      |      |            |        |      |               |                                       |      |          |     |
| Nr i | Rows: 360, Nr Columns: 3                |                             | View Data I                  | File Info 🛛 🖡         | telp 🤊 Undo      | C Redo      | $\times$ | 0.4  |            |        |      |               | Λ'                                    |      | ACatibro | tia |
|      | Set Column Na                           | ne                          |                              | Sm                    | ooth Data        |             | 34       | 1    | - Exper    | imenta | data |               |                                       |      |          |     |
|      | Goto Line                               |                             | Change Number of Data Points |                       |                  |             | 0.35     |      |            | 1      | /    | <u>.</u>      |                                       |      |          |     |
|      | Make Column Start from 0                |                             |                              | Multiply or Add Cells |                  |             | æ        | 0.55 |            |        |      | 1             |                                       |      |          |     |
|      | Column 1                                | Co                          | lumn 2                       |                       | Column 3         | *           |          |      |            |        |      |               |                                       |      | 0.000    |     |
| 1    | 0                                       | 0                           |                              | 0                     |                  |             |          | 0.3  |            |        |      |               | Ì                                     | -\   | -        |     |
| 2    | 9.78343195266                           | 0.0016534                   |                              | 0.4328                | 1                |             | 57       |      |            |        | 1    |               | -                                     |      | -        |     |
| 3    | 19.7625248521                           | 0.0033398667                |                              | 0.7629                | 9                |             | - Sec    |      |            |        | 1    |               |                                       |      |          |     |
| 4    | 29.736883432                            | 0.0050255333                |                              | 1.0410                | 2                |             | 162      | 0.25 |            |        | 1    |               |                                       |      |          |     |
| 5    | 39.7203153846                           | 0.0067127333                |                              | 1.3208                | 8                |             |          | ~    |            |        |      |               |                                       |      |          |     |
| 6    | 49.7017751479                           | 0.0083996                   |                              | 1.5692                | 3                |             |          | E    |            |        |      | -             |                                       |      | 1        |     |
| 7    | 59.6856017751                           | 0.0100868667                |                              | 1.7943                | 3                |             |          | 0.2  |            | 1      | 1    |               | i i i i i i i i i i i i i i i i i i i |      | N        | æ   |
| 8    | 69.659960355                            | 0.0117725333                |                              | 1.9562                | 3                |             | 3        | ŭ    |            |        |      |               |                                       |      |          |     |
| 9    | 79.6414201183                           | 0.0134594                   |                              | 2.1386                | 8                |             |          | 0.15 |            |        |      |               | 1                                     |      | l        |     |
| 10   | 89.6252467456                           | 0.0151466667                |                              | 2.3390                | 3                |             |          | 0.15 |            |        |      |               |                                       |      |          |     |
| 11   | 99.6043390533                           | 0.0168331333                |                              | 2.5166                | 4                |             |          |      |            |        |      |               | -                                     |      | -        |     |
| 12   | 109.581065089                           | 0.0185192                   |                              | 2.6518                | s                |             |          | 0.1  | /          |        |      |               |                                       |      |          |     |
| 13   | 119.562524852                           | 0.0202060667                |                              | 2.8199                | 1                |             |          | 0.00 |            |        |      | 1             | 1                                     |      |          |     |
| 14   | 129.543984024                           | 0.0218929333                |                              | 2.9864                | 4                |             |          |      |            |        |      | 1             | 1                                     |      |          |     |
| 15   | 3 139.525443787                         | 0.0235798                   |                              | 3.0637                | 2                |             |          | 0.05 | 1          |        |      | in the second |                                       |      | ani nono | -   |
| 16   | 5 149.504536686                         | 0.0252662667                |                              | 3.2143                | 2                |             |          |      |            |        |      |               |                                       |      |          |     |
| 17   | 159.483628994                           | 0.0269527333                |                              | 3.3494                | 4                |             |          |      |            |        |      |               |                                       |      |          |     |
| 18   | 169.462327219                           | 0.0286391333                |                              | 3.4842                | 4                |             |          | 0    | 500        | 1000   | 1500 | 2000          | 2500                                  | 3000 | 3500     | -   |
| 19   | 179.44852071                            | 0.0303268                   |                              | 3.5852                |                  |             |          |      |            |        | C    | olumn         | 1                                     |      |          |     |
| *Rig | ight click after selecting a group of e | ells for more data options. |                              |                       |                  |             |          | 3    | (-Axis: Co | lumn 1 | * Y. | Axis: Co      | lumn 2                                | •    |          |     |

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.

| Data |                          |              | Column Name                     | Graph                              |
|------|--------------------------|--------------|---------------------------------|------------------------------------|
| File | name: TensionData1.txt   |              | Time                            | 54                                 |
| Nr R | Rows: 360, Nr Columns: 3 | View         | True Strain                     | 0.4                                |
|      | Set Column Nam           | ne           | O Engineering Strain            | 34 Experimental data               |
|      | Goto Line                | 1            | O True Stress                   |                                    |
|      | Make Column Start        | from 0       | Engineering Stress              | E C.35                             |
|      | Column 1                 | Column 2     | O Transverse Strain             |                                    |
| 1    | 0                        | 0            | Engineering Storage Modulus     | 0.3                                |
| 2    | 9.78343195266            | 0.0016534    | Engineering Loss Modulus        |                                    |
| 3    | 19.7625248521            | 0.0033398667 | Engineering Strain Amplitude    |                                    |
| 4    | 29.736883432             | 0.0050255333 | Engineering Mean Strain         | 0.25                               |
| 5    | 39.7203153846            | 0.0067127333 | Frequency                       | N                                  |
| 6    | 49.7017751479            | 0.0083996    |                                 |                                    |
| 7    | 59.6856017751            | 0.0100868667 | O Place                         | ₹ <sup>0.2</sup>                   |
| 8    | 69.659960355             | 0.0117725333 | Obsplacement                    |                                    |
| 9    | 79.6414201183            | 0.0134594    | <ul> <li>Temperature</li> </ul> | 0.15                               |
| 10   | 89.6252467456            | 0.0151466667 | O Fatigue Min Stress            |                                    |
| 11   | 99.6043390533            | 0.0168331333 | O Fatigue Max Stress            |                                    |
| 12   | 109.581065089            | 0.0185192    | O Fatigue Cycles                | 0.1                                |
| 13   | 119.562524852            | 0.0202060667 | O Other: Column 1               |                                    |
| 14   | 129.543984024            | 0.0218929333 |                                 |                                    |
| 15   | 139.525443787            | 0.0235798    | © <u>C</u> ancel ✓ <u>O</u> K   | 0.05                               |
| 16   | 149.504536686            | 0.0252662667 | 3.21432                         |                                    |
| 17   | 159.483628994            | 0.0269527333 | 3.34944                         |                                    |
| 18   | 169.462327219            | 0.0286391333 | 3.48424                         | 0 500 1000 1500 2000 2500 3000 350 |
| 19   | 179.44852071             | 0.0303268    | 3.5852                          | Column 1                           |

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.

| Create | e Data Load Data File Sav | e Data Save Data File As | Reload Data File | Clear Table | Create Load Case    | Preferences |           |                            |      |         |        |                      |      |         |               |          |
|--------|---------------------------|--------------------------|------------------|-------------|---------------------|-------------|-----------|----------------------------|------|---------|--------|----------------------|------|---------|---------------|----------|
| Data   |                           |                          |                  | 1           |                     |             | Graph     |                            |      |         |        |                      |      |         |               |          |
| File   | e name: TensionData1.txt  |                          |                  | -           |                     |             | 12        |                            |      |         |        |                      |      |         |               |          |
| Nr     | Rows: 360, Nr Columns: 3  |                          | View Data        | File Info   | Help 🤊 Undo         | C Redo      | ×         | 0.4                        |      |         |        |                      | Λ    |         | ACatibro      | otio     |
|        | Set Colu                  | mn Name                  |                  | Sn          | nooth Data          |             | 34        |                            | Expe | rimenta | l data |                      | 1    |         | -             |          |
|        | Goto                      | Line                     |                  | Change Nu   | mber of Data Points |             | Q         | 0.35                       |      |         |        |                      |      |         |               |          |
|        | Make Colum                | nn Start from 0          |                  | Multip      | ly or Add Cells     |             |           | 0.55                       |      |         |        | 1                    |      |         |               |          |
|        | Time                      | Eng                      | ineering Strain  |             | Engineering Stro    | ess *       |           |                            |      |         |        |                      |      |         | -             |          |
| 1      | 0                         | 0                        |                  | 0           |                     |             |           | 0.3                        |      |         |        |                      |      | · · · · |               |          |
| 2      | 9.78343195266             | 0.0016534                |                  | 0.432       | 81                  |             | 573       |                            |      | -       |        | 1                    | i.   |         | -             |          |
| 3      | 19.7625248521             | 0.0033398667             |                  | 0.762       | 99                  |             | - Charles |                            |      |         | 1      |                      |      |         |               |          |
| 4      | 29.736883432              | 0.0050255333             |                  | 1.041       | 02                  |             |           | . <b>⊆</b> <sup>0.25</sup> |      |         | 1      |                      |      |         |               |          |
| 5      | 39.7203153846             | 0.0067127333             |                  | 1.320       | 88                  |             |           | stra                       |      |         |        |                      |      | 19      | N.            |          |
| 6      | 49.7017751479             | 0.0083996                |                  | 1.569       | 23                  |             |           | 5u                         |      |         |        |                      |      |         | 1             |          |
| 7      | 59.6856017751             | 0.0100868667             |                  | 1.794       | 33                  |             |           |                            |      | /       |        | 1                    | i.   |         |               | -        |
| 8      | 69.659960355              | 0.0117725333             |                  | 1.956       | 23                  |             |           | ib                         |      |         |        | -                    |      |         |               |          |
| 9      | 79.6414201183             | 0.0134594                |                  | 2.138       | 68                  |             |           | <del>ل</del> ے 15 م        |      |         |        |                      |      |         | ļ             |          |
| 10     | 89.6252467456             | 0.0151466667             |                  | 2.339       | 03                  |             |           | 0.15                       |      |         |        |                      |      |         |               |          |
| 11     | 99.6043390533             | 0.0168331333             |                  | 2.516       | 64                  |             |           |                            |      |         |        | 1                    |      |         | -             |          |
| 12     | 109.581065089             | 0.0185192                |                  | 2.651       | 85                  |             |           | 0.1                        |      |         |        |                      |      |         |               |          |
| 13     | 119.562524852             | 0.0202060667             |                  | 2.819       | 91                  |             |           |                            |      |         |        |                      | ł    |         | -             |          |
| 14     | 129.543984024             | 0.0218929333             |                  | 2.986       | 44                  |             |           |                            |      |         |        |                      |      |         |               |          |
| 15     | 139.525443787             | 0.0235798                |                  | 3.063       | 72                  |             |           | 0.05                       | 1    |         |        | in o naik (sen neero | +    |         | -ainti-Becomo | , initia |
| 16     | 149.504536686             | 0.0252662667             |                  | 3.214       | 32                  |             |           |                            |      |         |        |                      |      |         |               |          |
| 17     | 159.483628994             | 0.0269527333             |                  | 3.349       | 44                  |             |           |                            |      |         |        |                      |      |         |               |          |
| 18     | 169.462327219             | 0.0286391333             |                  | 3.484       | 24                  |             |           | 00                         | 500  | 1000    | 1500   | 2000                 | 2500 | 3000    | 3500          | 4        |
| 19     | 179.44852071              | 0.0303268                |                  | 3.585       | 2                   |             |           |                            |      |         |        | Time                 |      |         |               |          |

# **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.

| Contents of the Experimental       | Data File             |    |                       | ? X                     |
|------------------------------------|-----------------------|----|-----------------------|-------------------------|
| Experimental Data File             |                       |    | Graph                 |                         |
| Name of experimental data file: T  | ension_0_00017_s.tx   | t  | 400                   |                         |
| (The experimental file contains 35 | 6 rows and 3 columns) |    | - (experimental data) | ACalibration 🔀          |
| Numer of rows of data to include:  | 356                   | \$ |                       |                         |
| View Data File                     |                       |    | 350 -                 |                         |
| Time-Strain-Stress Data            |                       |    | 200                   |                         |
| Time Column:                       | 1                     | \$ | 300                   |                         |
| Strain Column:                     | 2                     | \$ |                       |                         |
| Stress Column:                     | 3                     | \$ | 250                   |                         |
| Transverse Strain Column:          | 3                     | 4  | 2                     |                         |
| Temperature Columo:                | 3                     | A  | I m                   |                         |
|                                    |                       |    |                       | 250 300 350 400<br>mber |
|                                    |                       |    | X-Axis: Row Number 🔻  | Y-Axis: Row Number 🔻    |
|                                    |                       |    |                       | OK Cancel               |

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.

| 🛃 Load Case Setup                                   |   | ? ×    |
|---|---|--------|
| Load Case Type: Experimental Data (time, o, c)      | Load Case Name: Tension_0_00017_s           |        |
| Experimental Data Loading Mode Time Steppin         | ng Pot Styles Pitness Weights Miscellaneous |        |
| Experimental<br>Set Experimental Line Color JCopy ( | Color to Predicted_                         |        |
| Experimental Line Width: 2.20                       |   |        |
| Experimental Line Style: Solid                      |   |        |
| Experimental Marker Style: (none) 💌                 | Number of Markers to Plot: 356 🔹            |        |
| Predicted   |   |        |
| Set Predicted Line Color †Copy Colo                 | for to Experimental t                       |        |
| Predicted Line Width: 2.20 0                        |   |        |
| Predicted Line Style: Solid                         |   |        |
| Predicted Marker Style: (none)                      | Number of Markers to Plot: 356 🗘            |        |
|   |   |        |
|   |   |        |
|   | Save  | Cancel |

# 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 <u>Three</u> <u>Network</u> (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.

| open  | MCal-File S  | ave MCal-File  | Import Materi   | ial Model               | Run Once Ru   | un Calibration Pause Calibration Stop Calibration Parametric Study Export Model Save Predictions Preferences Create Report                                  |
|---|--|--|---|-------------------------|---|---|
| Exper   | rimental Test  | s / Load Case!   |   |                         |   | Graph Window  |
| +   | - ON OFF   | Etiq   |   |                         |   |   |
|   | S Fit  |  | Load  | Case Name               |   | 10.5  |
| 1   | <u> </u>   | Tensi  | onData1   |                         |   | TensionData1 (experimental)   |
| 2   | - 1  | 🖪 Tensi  | onData2   |                         | A   | TensionData2 (experimental)   |
| Mater   | rial Models  | X <sub>0</sub> 🖉 💽<br>rial Model F   |   | Tib Fit<br>ree-Network  |   | Stranger 2.5  |
| 1   | Name<br>muA  | Value<br>38.1574688  | Lower Bound   | Upper Bound             | Optimize  |   |
| 1   | Name<br>muA<br>thetaHat  | Value<br>38.1574688<br>0   | Lower Bound   | Upper Bound             | Optimize  | 0 0.05 0.1 0.15 0.2 0.25 0.3 0  |
| 1 2 3   | Name<br>muA<br>thetaHat<br>lambdaL   | Value<br>38.1574688<br>0<br>5.11   | Lower Bound   | Upper Bound             | Optimize<br>V 1<br>V 3  | 0 0.05 0.1 0.15 0.2 0.25 0.3 0<br>True Strain   |
| 1<br>2<br>3<br>4  | Name<br>muA<br>thetaHat<br>lambdaL<br>kappa  | Value<br>38.1574688<br>0<br>5.11<br>408.544385   | Lower Bound   | Upper Bound             | Optimize<br>V 1<br>V 3  | 0 0.05 0.1 0.15 0.2 0.25 0.3 0<br>True Strain   |
| 1<br>2<br>3<br>4<br>5                                       | Name<br>muA<br>thetaHat<br>lambdaL<br>kappa<br>tauHatA   | Value<br>38.1574688<br>0<br>5.11<br>408.544385<br>4.68544145   | Lower Bound<br>0<br>1<br>0<br>0   | Upper Bound             | Optimize  | 0 0.05 0.1 0.15 0.2 0.25 0.3 0<br>True Strain Results   |
| 1<br>2<br>3<br>4<br>5<br>6                                  | Name<br>muA<br>thetaHat<br>lambdaL<br>kappa<br>tauHatA<br>a  | Value<br>38.1574688<br>0<br>5.11<br>408.544385<br>4.68544145<br>0  | Lower Bound<br>0<br>1<br>0<br>0   | Upper Bound             | Optimize  | Q 0.05 0.1 0.15 0.2 0.25 0.3 C<br>True Strain Results Runtime Output Comments Optimization Progress Calibrated Models                                       |
| 1<br>2<br>3<br>4<br>5<br>6<br>7                             | Name<br>muA<br>thetaHat<br>lambdaL<br>kappa<br>tauHatA<br>a<br>mA  | Value<br>38.1574688<br>0<br>5.11<br>408.544385<br>4.68544145<br>0<br>9.729   | Lower Bound 1<br>0<br>1<br>0<br>0<br>1.1  | 10<br>25                | Optimize  | 0<br>0.05<br>0.1<br>0.15<br>0.2<br>0.25<br>0.3<br>0<br>True Strain<br>Results<br>Results<br>Runtime Output Comments Optimization Progress Calibrated Models |
| 1<br>2<br>3<br>4<br>5<br>6<br>7<br>8                        | Name<br>muA<br>thetaHat<br>lambdaL<br>kappa<br>tauHatA<br>a<br>mA<br>n                                   | Value<br>38.1574688<br>0<br>5.11<br>408.544385<br>4.68544145<br>0<br>9.729<br>0  | Lower Bound 1<br>0<br>1<br>0<br>0<br>1.1<br>0   | Upper Bound<br>10<br>25 | Optimize  | Comments Optimization Progress Calibrated Models  |
| 1<br>2<br>3<br>4<br>5<br>6<br>7<br>8<br>9                   | Name<br>muA<br>thetaHat<br>lambdaL<br>kappa<br>tauHatA<br>a<br>mA<br>n<br>muBi                           | Value 38.1574688 0 5.11 408.544385 4.68544145 0 9.729 0 38.1574688   | Lower Bound (<br>0<br>1<br>0<br>0<br>0<br>1.1<br>0<br>0<br>0  | Upper Bound<br>10<br>25 | Optimize  | Comments Optimization Progress Calibrated Models  |
| 1<br>2<br>3<br>4<br>5<br>6<br>7<br>8<br>9<br>10             | Name<br>muA<br>thetaHat<br>lambdaL<br>kappa<br>tauHatA<br>a<br>mA<br>n<br>muBi<br>muBf                   | Value 38.1574688 0 5.11 408.544385 4.68544145 0 9.729 0 38.1574688 19.0787344  | Lower Bound (<br>0<br>1<br>0<br>0<br>0<br>1.1<br>0<br>0<br>0<br>0<br>0  | 10<br>25                | Optimize  | 0<br>0.05<br>0.1<br>0.15<br>0.2<br>0.25<br>0.3<br>0<br>True Strain<br>Results<br>Runtime Output Comments Optimization Progress Calibrated Models            |
| 1<br>2<br>3<br>4<br>5<br>6<br>7<br>8<br>9<br>10<br>11       | Name<br>muA<br>thetaHat<br>lambdaL<br>kappa<br>tauHatA<br>a<br>mA<br>mA<br>n<br>muBi<br>muBf<br>beta     | Value<br>38.1574688<br>0<br>5.11<br>408.544385<br>4.68544145<br>0<br>9.729<br>0<br>38.1574688<br>19.0787344<br>11.122              | Lower Bound<br>0<br>1<br>0<br>0<br>1.1<br>0<br>0<br>0<br>0<br>0   | Upper Bound             | Optimize           V           I           V           S           V< | 0<br>0.05<br>0.1<br>0.15<br>0.2<br>0.25<br>0.3<br>0<br>True Strain<br>Results<br>Runtime Output Comments Optimization Progress Calibrated Models            |
| 1<br>2<br>3<br>4<br>5<br>6<br>7<br>8<br>9<br>10<br>11<br>11 | Name<br>muA<br>thetaHat<br>lambdaL<br>kappa<br>tauHatA<br>a<br>mA<br>mA<br>mB<br>muBf<br>beta<br>tauHatB | Value<br>38.1574688<br>0<br>5.11<br>408.544385<br>4.68544145<br>0<br>9.729<br>0<br>38.1574688<br>19.0787344<br>11.122<br>9.3708829 | Lower Bound<br>0<br>1<br>1<br>0<br>0<br>0<br>1<br>1<br>0<br>0<br>0<br>0<br>0<br>0<br>0<br>1<br>1<br>0<br>0<br>0<br>0<br>0<br>0<br>0<br>0<br>0<br>0<br>0<br>0<br>0 | 10<br>25                | Optimize           V           1           V< | Comments Optimization Progress Calibrated Models  |

# **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.

|                             |  |                                    |  |  | Load Case Set                             | tup                                       |                                  |                                   |                                       |                                  | 8                  |
|-----------------------------|--|------------------------------------|--|--|---|---|----------------------------------|-----------------------------------|---------------------------------------|----------------------------------|--------------------|
| Load Case Type              | e: Virtual Experir                               | ment (Segmen                       | ts) 🔹                                    | Load Case <u>N</u>                             | ame:                                      |   |                                  |                                   |                                       | Insert degr                      | ree (°) symbol     |
| Segments                    | Loading Mode                                     | Plot Styles                        | Fitness Weight                           | Miscellaneous                                  |   |   |                                  |                                   |                                       |                                  |                    |
| Optional I                  | experimental Data                                |                                    |  |  |   |   |                                  |                                   |                                       |                                  |                    |
| Load Expe                   | rimental File                                    | Export D                           | ata Revert to Ori                        | ninal Data Remov                               | e Original Data                           |   |                                  |                                   |                                       |                                  |                    |
|                             |  |                                    |  | <u>\</u>                                       |   |   |                                  |                                   |                                       |                                  |                    |
| Strain Type                 | True Strain                                      |                                    | Stress Type:                             | True Stress                                    | *   |   |                                  |                                   |                                       |                                  |                    |
| A virtual lo<br>that the ex | ad case can be use<br>perimental data th<br>used | ed for material<br>nat is loaded h | model calibration<br>ere is only used to | if the applied virtua<br>calculate a fitness v | al load history is s<br>value of the mode | similar to the exp<br>el prediction. In m | erimental load<br>nost cases the | l history specil<br>option to use | ied on the Experi<br>experimental dat | mental Data ta<br>a for a Segmen | b. Note<br>ts load |
|                             | ascal  |                                    |  |  |   |   |                                  |                                   |                                       |                                  |                    |
|                             |  |                                    |  |  |   |   |                                  |                                   |                                       |                                  |                    |
|                             |  |                                    |  |  |   |   |                                  |                                   |                                       |                                  |                    |
|                             |  |                                    |  |  |   |   |                                  |                                   |                                       | Add C                            | amont              |
|                             |  |                                    |  |  |   |   |                                  |                                   |                                       | Add S                            | egment             |
|                             |  |                                    |  |  |   |   |                                  |                                   |                                       | Remove                           | Segment            |
|                             |  |                                    |  |  |   |   |                                  |                                   |                                       | <u>E</u> dit S                   | egment             |
|                             |  |                                    |  |  |   |   |                                  |                                   |                                       | Move Se                          | gment Up           |
|                             |  |                                    |  |  |   |   |                                  |                                   |                                       | Move Seg                         | ment Down          |
|                             |  |                                    |  |  |   |   |                                  |                                   |                                       |                                  |                    |
|                             |  |                                    |  |  |   |   |                                  |                                   |                                       |                                  |                    |
|                             |  |                                    |  |  |   |   |                                  |                                   |                                       |                                  |                    |
|                             |  |                                    |  |  |   |   |                                  |                                   |                                       | ⊘ <u>C</u> ancel                 | 🖺 Save             |

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

| Specify Segment Properties                                       | ?    | ×  |
|--|------|----|
| Control  |      |    |
| Run: Engineering Strain Rate Value: -0.01                        |      |    |
| Target   |      |    |
| Until: Engineering Strain 🔻 Value: -0.1                          |      |    |
| Use a second target condition (stop if either condition is true) |      |    |
| Or Until: Segment Time 🛛 🗸 Greater Than or Equal 👻 Value: 0      |      |    |
| Temperature  |      |    |
| Start Temperature: 293.00 🗲 End Temperature: 293.00 ¢            |      |    |
| Time Stepping  |      |    |
| Specify the minimum number of time increments: 300 -             |      |    |
| O Manually specify the time increment sizes:                     |      |    |
| Min allowed time increment: 0.0033333333333                      |      |    |
| Max allowed time increment: 0.033333333333                       |      |    |
| Initial time increment: 0.03333333333                            |      |    |
| Save   | Cano | el |

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.

| D Load Case Setup  | ? ×               |
|--|-------------------|
| Load Case Type: Virtual Experiment (Segments)   Load Case Name:  |                   |
| Segments Loading Mode Plot Styles Fitness Weight Miscellaneous   |                   |
| Coptional Experimental Data  |                   |
| Load Experimental File Export Data Revert to Organal Data  |                   |
| Stran Type: True Stran Y Stress Type: True Stress Y  |                   |
| A virtual load case can be used for material model calibration if the applied virtual load history is similar to the experimental load history specified on the Experimental Data tab. Note that the experimental data that is loaded here is only used to calculate a fitness value prediction. In most cases the option to use experimental data for a Segments load case it not used. | of the model      |
| [8] Segment L eng strain rate=-0.01 until eng strains=-0.1 [Iemg=260]  |                   |
|  |                   |
|  |                   |
|  |                   |
|  |                   |
|  |                   |
|  |                   |
|  | Add Segment       |
|  | Remove segment    |
|  | Move Segment Lin  |
|  | Move Seament Down |
|  |                   |
|  |                   |
|  |                   |
|  |                   |
|  |                   |
|  |                   |
|  | 1                 |
|  | Save Cancel       |

The second loading segment has constant strain for 60 seconds.

• Click Save.

| Specify Segment Properties                              |                     | ?   | ×   |
|---|---------------------|-----|-----|
| Control   |                     |     |     |
| Run: Engineering Strain Rate Value: 0.0                 |                     |     |     |
| Target  |                     |     |     |
| Until: Segment Time  Value: 60                          |                     |     |     |
| Use a second target condition (stop if either condition | is true)            |     |     |
| Or Until: Engineering Strain 🍸 Greater Than             | or Equal 🔻 Value: 0 |     |     |
| Temperature   |                     |     |     |
|   |                     |     |     |
| Start Temperature: 293.00 🖨 End Tempera                 | ture: 293.00 🖨      |     |     |
|   |                     |     |     |
| Time Stepping   |                     |     |     |
| Specify the minimum number of time increments: 30       | 0                   |     |     |
| O Manually specify the time increment sizes:            |                     |     |     |
| Min allowed time increment: 0.02                        |                     |     |     |
| Max allowed time increment: 0.2                         |                     |     |     |
| Initial time increment: 0.2                             |                     | 1   |     |
|   | Save                | Can | cel |

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.



# 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.

| Export M  | Naterial Parameters   |  | 8 |
|---|---|--|---|
| Export Parameter Format:<br>Abaqus inp-file<br>Abaqus CAE script<br>ANSYS (APDL dat-format)<br>ANSYS (XML-format)<br>LS-DYNA<br>COMSOL (csv-file)<br>MSC.Marc (dat-file)<br>PolyUMod External File<br>MCalibration Template<br>RADIOSS (txt-file) | Units:<br>Use the following units<br>material parameters.<br>Unit for length:<br>Unit for force:<br>Unit for time:<br>Unit for temperature: | s when exporting the<br>mm (millimeter)<br>N (Newton)<br>s (seconds)<br>K (Kelvin) | • |
|   |   | Cancel   | e |

# Import Model Into Abaqus/CAE

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

| 🚔 Run Scrip        | ot                            | x  |
|--------------------|-------------------------------|----|
| Directory:         | 🗎 Temp 💽 🗈 🟠 🥕 👉 🧱 🖭 î        |    |
| 🗀<br>🔝 simulatio   | on_material_script.py         |    |
| <u>F</u> ile Name: | simulation_material_script.py |    |
| File Filter:       | Python Script (*.py)          | el |

The model tree then contains the calibrated material model.

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

| 🗆 🎎 Models (1)           | * |  |  |  |  |  |  |
|--------------------------|---|--|--|--|--|--|--|
| B Model-1                |   |  |  |  |  |  |  |
| - 🕒 Parts                |   |  |  |  |  |  |  |
| B 🔄 Materials (1)        |   |  |  |  |  |  |  |
| MCalibration material    |   |  |  |  |  |  |  |
| - 🕸 Calibrations         |   |  |  |  |  |  |  |
| - 🕏 Sections             |   |  |  |  |  |  |  |
| - 🏶 Profiles             |   |  |  |  |  |  |  |
| the <b>4</b> 2 Accomplia |   |  |  |  |  |  |  |
|                          |   |  |  |  |  |  |  |

### Import the Model Into ANSYS WB

Read the .dat file exported from MCalibration into ANSYS Mechanical as a command under Geometry  $\rightarrow$  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.

| A : Static Structural - Mechanical (ANSYS Mechanical)            |         |  |                                    |   |                      |                               |                 |        | 2   |
|--|---------|--|------------------------------------|---|----------------------|-------------------------------|-----------------|--------|-----|
| File Edit View Units Tools Help 🥥 🍠 Solve 💌 🗱 🕷                  | B + B   | 🖸 🐼 🖝 🖤 Worksheet - 🤽  |                                    |   |                      |                               |                 |        |     |
| ₹ / * @ • \$ • @ @ @ @ @ • \$ ÷ @ @                              | ( ) ( ) | 0, 12 /0, 8  |                                    |   |                      |                               |                 |        |     |
| E Show Vertices Wireframe Edge Coloring - A - A                  | - 1- 1  | - A- X H HThicken Annot  | tions "how black A Show (          | our dinate Sustems                      |                      |                               |                 |        |     |
| Commands wheneved instructed Reduction                           |         |  |                                    | and a systems                           |                      |                               |                 |        |     |
| Commando Salexporta assimporta de Merresin                       |         | - 4-   |                                    |   |                      |                               |                 |        |     |
| Outline  | Comma   | nds  |                                    |   |                      |                               |                 |        | -   |
| Project  | TBDATA, | 6, 1 ! VERB  |                                    |   |                      |                               |                 |        | ^   |
| E- Model (A4)  | TBDATA, | R 0 I VELEW  |                                    |   |                      |                               |                 |        |     |
| D . A fold   | TBDATA, | 9, 0 ! VINT  |                                    |   |                      |                               |                 |        |     |
| E Commands (ADDL)  | TREATA, | 10, 0 ! ORIENT   |                                    |   |                      |                               |                 |        |     |
| P d Coordinate Systems   | TBDATA, | 11, 33 ! NPROP   |                                    |   |                      |                               |                 |        |     |
| E de Mech  | TBDATA, | 12, 23 ! NHIST   |                                    |   |                      |                               |                 |        |     |
|  | TBDATA  | 14, 500 ! GKAP   | 2A                                 |   |                      |                               |                 |        |     |
| - Analysis Settings  | TBDATA, | 15, 0 ! FAILT  |                                    |   |                      |                               |                 |        |     |
| left   | TBDATA, | 16, 0 ! FAILV  |                                    |   |                      |                               |                 |        |     |
| - , , back   | TBDATA, | 17, 28.91 ! muA  |                                    |   |                      |                               |                 |        |     |
| - A bottom   | TBDATA  | 19, 5,27483 ! lamb   | daL                                |   |                      |                               |                 |        | 11  |
| -, A, right-move   | TBDATA. | 20, 4189.66 ! kapp   | a                                  |   |                      |                               |                 |        |     |
| 🗄 🦓 Solution (A6)  | TBDATA, | 21, 13.9036 ! tau8   | atA                                |   |                      |                               |                 |        |     |
|  | TBDATA, | 22, 0.000263973  | 1.4                                |   |                      |                               |                 |        |     |
|  | TREATA  | 24.0 !n  |                                    |   |                      |                               |                 |        |     |
|  | TRDATA, | 25, 152.599 ! muBi   |                                    |   |                      |                               |                 |        |     |
|  | TBDATA, | 26, 2.92555 ! mubf   |                                    |   |                      |                               |                 |        |     |
| Maximum Principal Stress   | TBDATA, | 27, 83.7523 ! beta   |                                    |   |                      |                               |                 |        |     |
|  | TBDATA, | 20, 9,67938 1 mB   | atb                                |   |                      |                               |                 |        |     |
| Normal Elastic Strain  | TREATA, | 30, 42.6211 ! muC  |                                    |   |                      |                               |                 |        |     |
| Norma Eastic Strain 2  | TBDATA, | . 31, 0 ! q  |                                    |   |                      |                               |                 |        |     |
| Datails of "Commands (ADDI)"                                     | TBDATA, | . 32, 0 ! alpha<br>. 33, 293 ! thet  | a0                                 |   |                      |                               |                 |        |     |
| Cetans of Commands (VPDC)  | -       |  |                                    |   |                      |                               |                 |        |     |
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| B Definition   |         | and a second sec |                                    |   |                      |                               |                 |        |     |
| Suppressed No  | Message | 15   |                                    |   |                      |                               |                 |        | # × |
| Target Mechanical APDL   | -       | Text   |                                    | Association                             | Timestamp            |                               |                 |        |     |
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| ARG2   |         |  |                                    |   |                      |                               |                 |        |     |
| ARG3   |         |  |                                    |   |                      |                               |                 |        |     |
| ARG4   |         |  |                                    |   |                      |                               |                 |        |     |
| ARGS   | - 10    |  |                                    |   |                      |                               |                 |        |     |
| A00  |         |  |                                    |   |                      |                               |                 |        |     |
| ARG8   |         |  |                                    |   |                      |                               |                 |        |     |
| ARG9   |         |  |                                    |   |                      |                               |                 |        |     |
|  |         |  |                                    |   |                      |                               |                 |        |     |
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#### **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.

| 0    |   |  |         |       |   | 1   | .Mod/tri   | unk/C   | ase Studie                              | s/MCalibrati                      | on_Introducti |
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| 14   |   | <legen< td=""><td>dColor&gt;</td><th>64f0f</th><th>0f0<td>gendCol</td><td>or&gt;</td><td></td><td>S</td><td></td><td></td></th></legen<>   | dColor> | 64f0f | 0f0 <td>gendCol</td> <td>or&gt;</td> <td></td> <td>S</td> <td></td> <td></td>                 | gendCol   | or>  |   | S                                       |                                   |               |
| 15   |   | <legen< td=""><td>dPos&gt;0&lt;</td><th>/lege</th><th>ndPos&gt;</th><td></td><td></td><td></td><td></td><td></td><td></td></legen<>  | dPos>0< | /lege | ndPos>  |   |  |   |   |                                   |               |
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| 10   |   | <legen< td=""><td>dShown&gt;</td><th>crue&lt;</th><th>/Legend</th><td>1 5 50</td><td></td><td>0.047</td><td>fitlahal For</td><td>**</td><td></td></legen<>                       | dShown> | crue< | /Legend   | 1 5 50  |  | 0.047   | fitlahal For                            | **                                |               |
| 19   |   | <fitla< td=""><td>belFont</td><th>Color</th><th>&gt;ff0000</th><td>00<td>LabelFor</td><td>ntCol</td><td>OF&gt;</td><td></td><td></td></td></fitla<>                              | belFont | Color | >ff0000   | 00 <td>LabelFor</td> <td>ntCol</td> <td>OF&gt;</td> <td></td> <td></td>             | LabelFor   | ntCol   | OF>                                     |                                   |               |
| 20   |   | <filen< td=""><td>aneLabe</td><th>Font</th><th>&gt;Calibr</th><td>1,9,-1,</td><td>5,50,0,0</td><td>0,0,0</td><td>,0<td>eLabelFont&gt;</td><td>8</td></td></filen<>               | aneLabe | Font  | >Calibr   | 1,9,-1,   | 5,50,0,0   | 0,0,0   | ,0 <td>eLabelFont&gt;</td> <td>8</td>   | eLabelFont>                       | 8             |
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| 37   |   | Granh>   | quantit | yarru | e stres   | s (nea)   | yax150</td <td>quant.</td> <td>ILY?</td> <td></td> <td></td>     | quant.  | ILY?                                    |                                   |               |
| 38   | 1.00  | ai apir-   |         |       |   |   |  |   |   |                                   |               |
| 39 ¥ | <   | LoadCase   | type="  | exper | imental   | data*>  | ÷  |   |   |                                   |               |
| 40   |   | <name></name>  | Tension | 0 01  | 7_s <td>&lt;98</td> <td>1212-01100</td> <td></td> <td></td> <td></td> <td></td>               | <98   | 1212-01100   |   |   |                                   |               |
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| EL.  | · · · · ·   | <exp_0< td=""><td>7467455</td><th>0000</th><th>9.76343</th><td>1925000</td><td>001, 19</td><td>, /625,</td><td>246521, 29.</td><td>/30883432,</td><td>39.720313384</td></exp_0<> | 7467455 | 0000  | 9.76343   | 1925000   | 001, 19  | , /625,   | 246521, 29.                             | /30883432,                        | 39.720313384  |
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| 47   |   | 498.   | 6165690 | 47 5  | 08 6003   | 94675   | 618 574  | 20118   | 4 628 5563                              | 13018 632                         | 537672781 E   |
| 40   |   | £00.   | A100340 | 11 7  | 00.0000   | 37011   | 710 270  | 10000   | 7, 020.3302                             | 13600 730                         | 337072701, 0  |

# **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.