# ANSYS material modeling: Hyperelastic material characterization

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# Overview

- The coefficients of strain energy potential can be calibrated by a few sets of simple stress state tests with a curve fitting procedure
- ANSYS implements both a linear and a nonlinear least-squares fit procedures for fitting the data
- The common test types include:
  - Uniaxial test
  - Equibiaxial test
  - Shear test (planar test)
  - Volumetric test

# Uniaxial Test

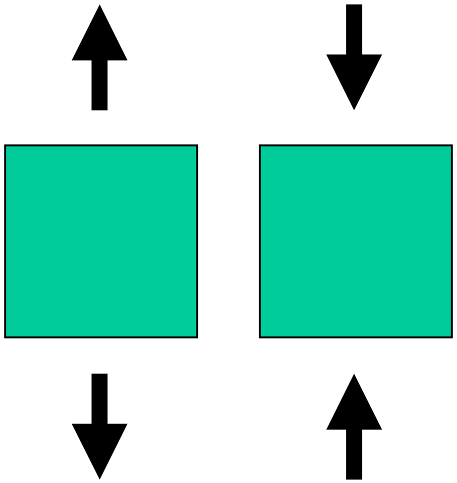
- Uniaxial test includes uniaxial tension and uniaxial compression.

Deformation state

$$\lambda_1 = \lambda_A \qquad \lambda_2 = \lambda_3 = \lambda_A^{-1/2}$$

Stress state

$$\sigma_A = 2\left(1 - \lambda_A^{-3}\right)\left(\lambda_A \frac{\partial U}{\partial I_1} + \frac{\partial U}{\partial I_2}\right)$$



$\lambda_A$ **is the uniaxial stretch ratio**

# Biaxial Test

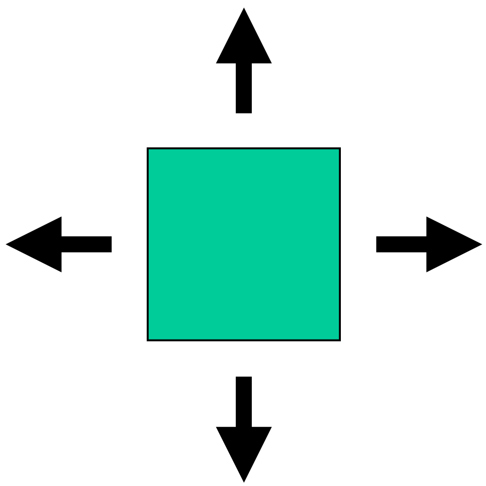
- biaxial test also includes tension and compression.

Deformation state

$$\lambda_1 = \lambda_2 = \lambda_A \qquad \lambda_3 = \lambda_A^{-2}$$

Stress state

$$\sigma_A = 2\left(\lambda_A - \lambda_A^{-5}\right)\left(\frac{\partial U}{\partial I_1} + \lambda_A^2 \frac{\partial U}{\partial I_2}\right)$$



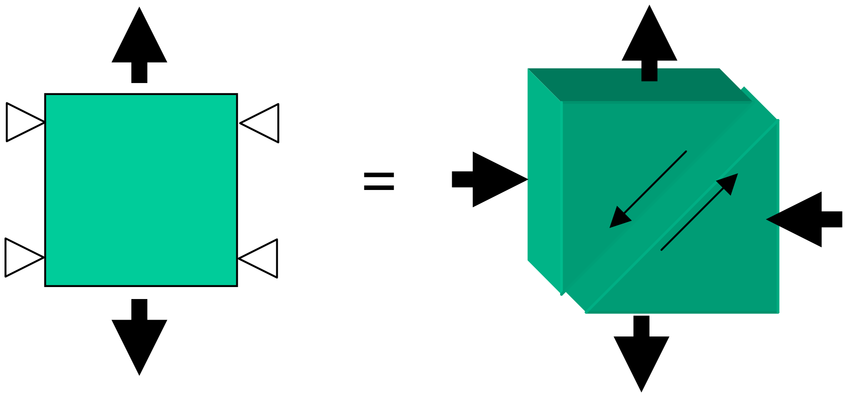
$\lambda_A$ **is the biaxial stretch ratio**

# Planar (pure shear) Test

- Planar test has the same stress state as the pure shear test.

Deformation state

$$\lambda_1 = \lambda_A \quad \lambda_2 = \lambda_A^{-1}$$
$$\lambda_3 = 1$$




Stress state

$$\sigma_A = 2\left(\lambda_A - \lambda_A^{-3}\right)\left(\frac{\partial U}{\partial I_1} + \frac{\partial U}{\partial I_2}\right)$$

$\lambda_A$ **is the stretch ratio in loading direction**

# Volumetric Test

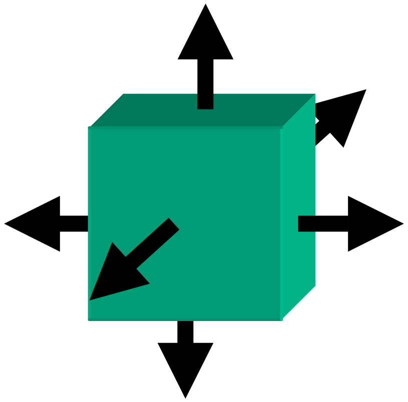
- Volumetric test.

Deformation state

$$\lambda_1 = \lambda_2 = \lambda_3 = \lambda_A = J^{1/3}$$

Stress state

$$\sigma_A = -p = \frac{\partial U}{\partial J}$$



# Curve Fitting Procedure

- Curve fitting algorithm
  - Unnormalized least squares fit

$$S = \sum_{i=1}^{NP} \left( \sigma_E - \sigma_A \right)^2$$

  - Normalized least squares fit

$$S = \sum_{i=1}^{NP} \left( 1 - \frac{\sigma_A}{\sigma_E} \right)^2$$

where: S = relative error

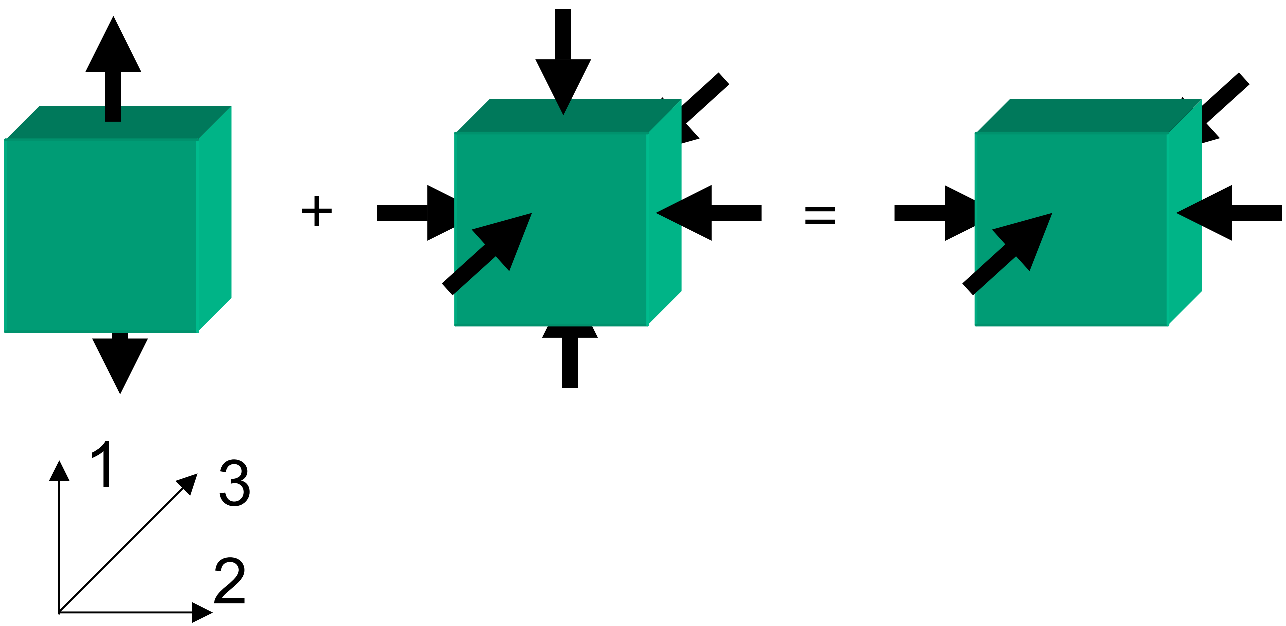
$\sigma_E$ = experimental stress values

# Curve Fitting Procedure

- Curve fitting algorithm
  - The material constants are determined by a least-squares procedure for a given set of experimental data, which minimizes the relative error, **S**.
  - The Mooney, Polynomial, Yeoh strain energy potentials are linear in terms of the constants. Therefore a linear least-squares fit procedure is used.
  - The Ogden, Arruda-Boyce, Gent strain energy potentials are nonlinear in terms of the constants. A nonlinear least-squares fitting procedure is needed. We use Marquard-Levenberg algorithm.

# Curve Fitting Procedure

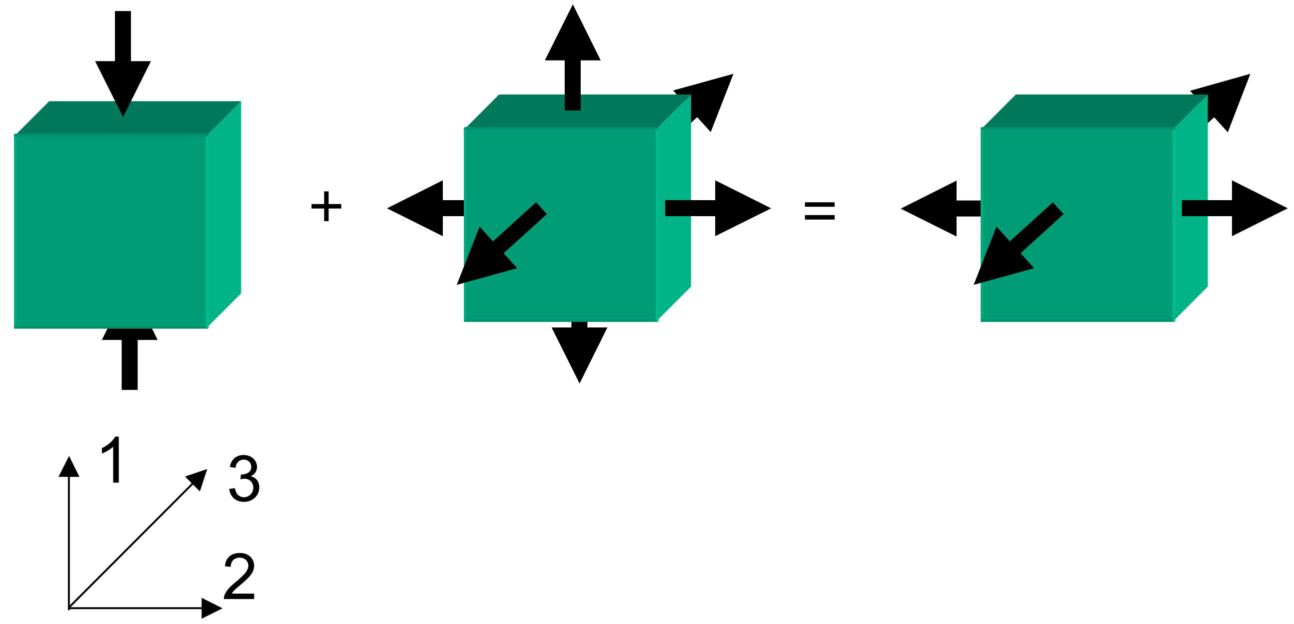
- Equivalent deformation modes
  - Uniaxial tension and equibiaxial compression




Add a hyperstatic stress does change the deformation mode

# Curve Fitting Procedure

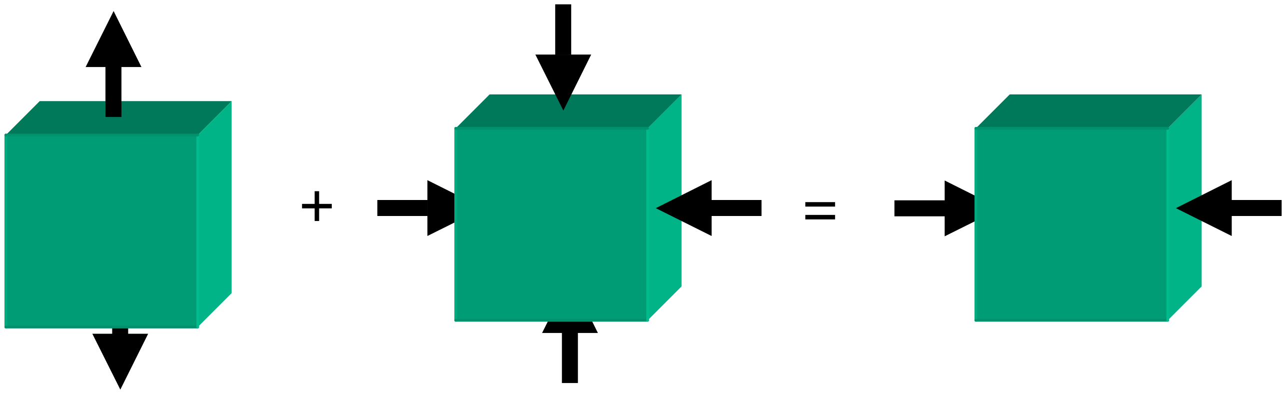
- Equivalent deformation modes
  - Uniaxial compression and equibiaxial tension

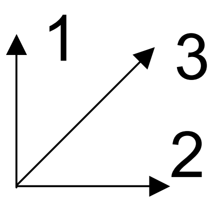



Add a hyperstatic stress does change the deformation mode

# Curve Fitting Procedure

- Equivalent deformation modes
  - Planar tension and Planar compression




$$\lambda_3 = 1$$

Add a hyperstatic stress does change the deformation mode

# Curve Fitting Procedure

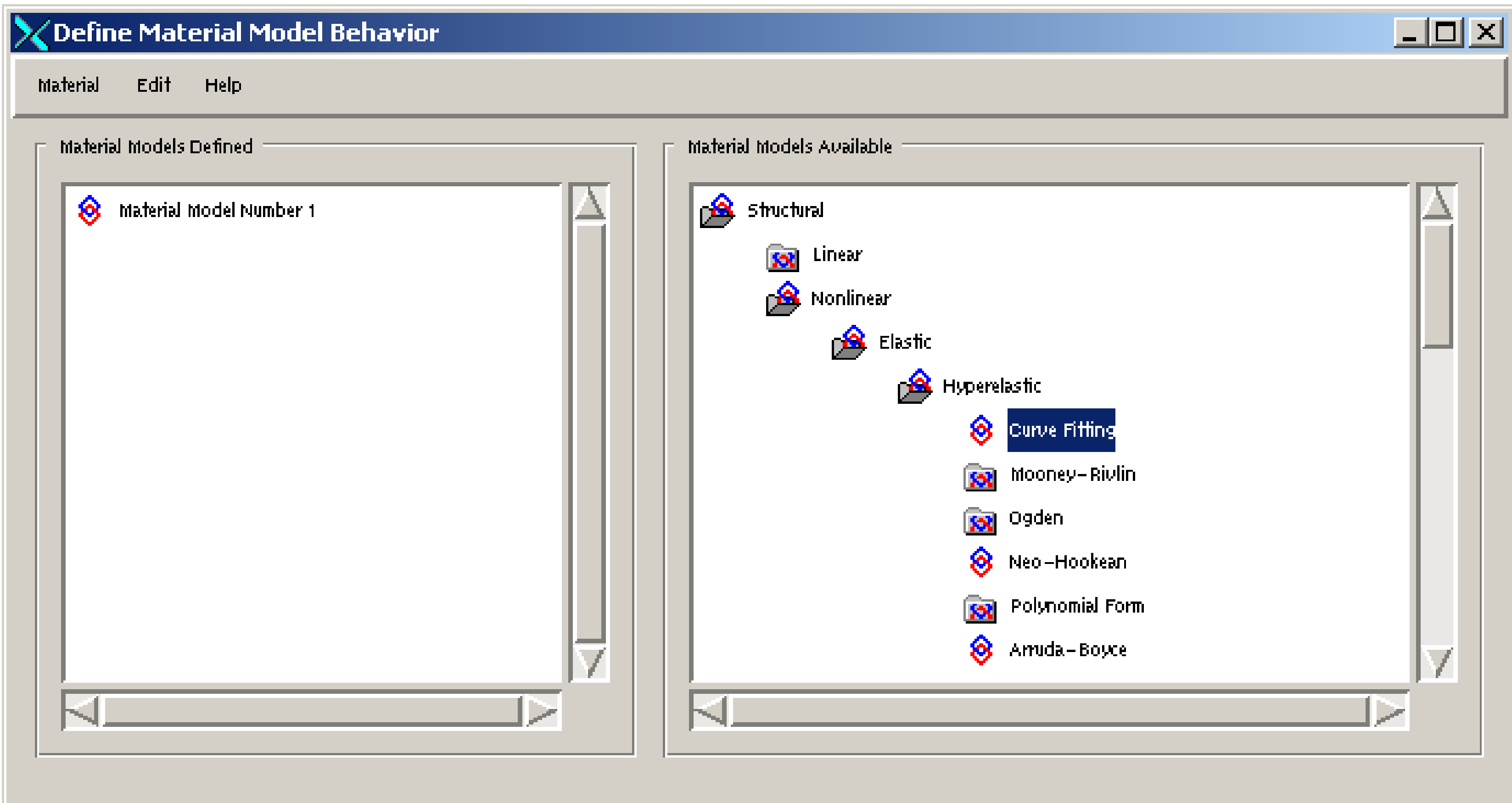
- Multiple types of test set
  - Hyperelastic material models in ANSYS are phenomenological and the parameters characterization relies on a least-squares fitting.
  - Multiple types of tests are essential to cover different deformation and to ensure the accuracy.

# Curve Fitting Procedure

- Procedures for determination of material constants
  - Input experimental data
  - Specify hyperelastic material option
  - Fit experimental data
  - Update the material data to ANSYS database
- Curve fitting procedure is accessible both from Material GUI and batch run.
  - Material GUI is a wizard type of application, which guides you through the whole process.
  - Command for batch
    - TBFT,Option1, Option2, Option3,…
      Option1 = EADD, FADD, SET, SOLV, PLOT, FSET

# Curve Fitting Procedure

- Material GUI

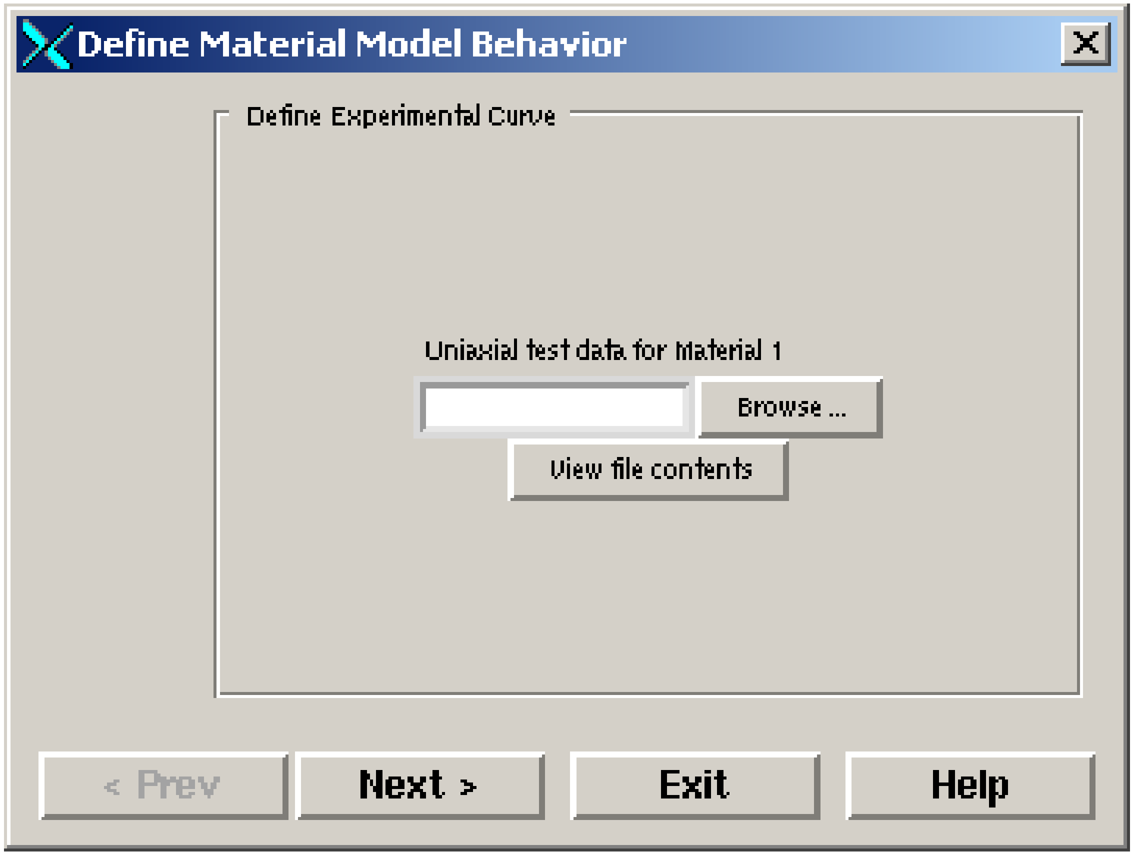


# Input Experimental data

- Command for Input uniaxial test data
  - TBFT, EADD, ID, option1, option2, option3, option4
  - Option1 = UNIA,BIAX, SHEA, or, VOLU
  - Option2 = name of file containing experimental data
  - Option3 = file name extension
  - Option4 = file directory

# Input Experimental data

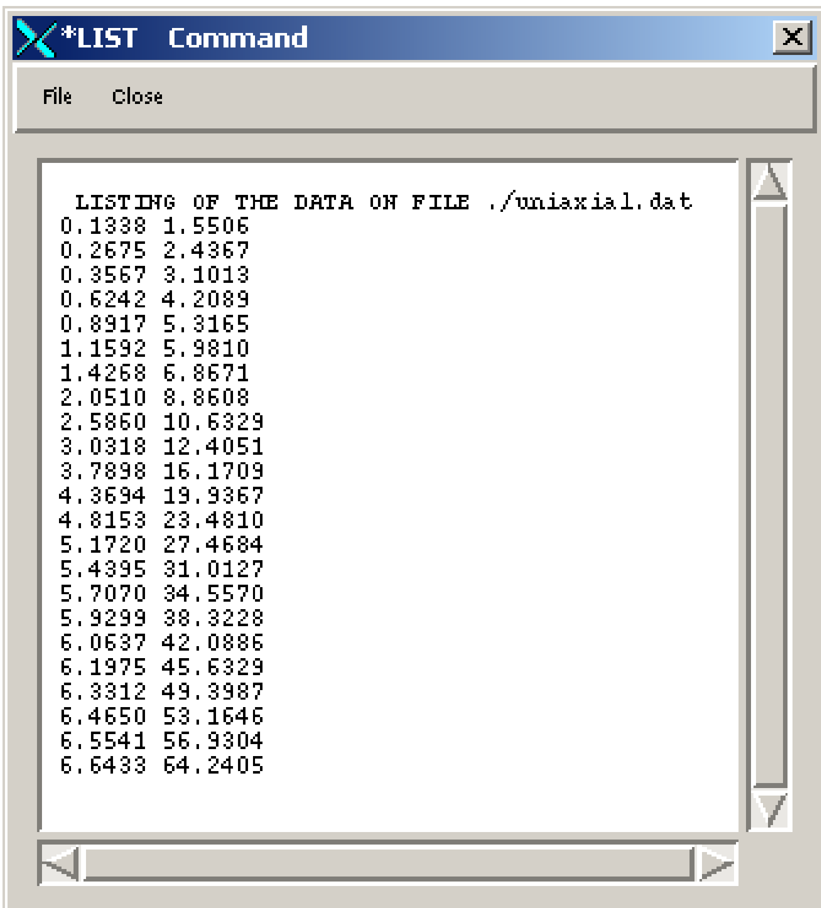
- Input uniaxial test data using GUI




- Enter filename that containing uniaxial experimental data, and/or click next.
- To skip a test simple click next
- Click view file contents to view the experimental from screen

# Input Experimental data

- Viewing input contents

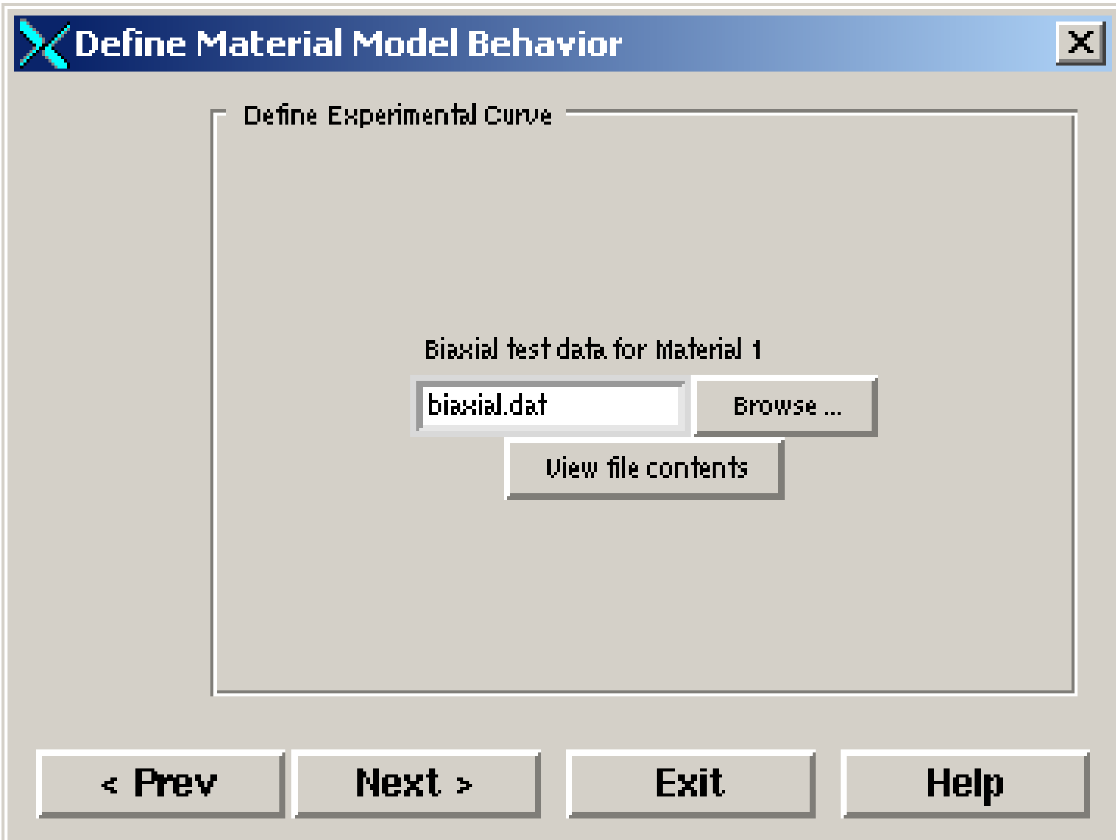



The input data is text file with data demilited with commas or spaces

| | |
|---|---|
| 0.13380 | 1.55060 |
| 0.26750 | 2.43670 |
| 0.35670 | 3.10130 |
| 0.62420 | 4.20890 |
| 0.89170 | 5.31650 |
| 1.15920 | 5.98100 |
| 1.42680 | 6.86710 |
| 2.05100 | 8.86080 |
| 2.58600 | 10.63290 |
| 3.03180 | 12.40510 |
| 3.78980 | 16.17090 |
| 4.36940 | 19.93670 |
| 4.81530 | 23.48100 |
| 5.17200 | 27.46840 |
| 5.43950 | 31.01270 |
| 5.70700 | 34.55700 |
| 5.92990 | 38.32280 |
| 6.06370 | 42.08860 |
| 6.19750 | 45.63290 |
| 6.33120 | 49.39870 |
| 6.46500 | 53.16460 |
| 6.55410 | 56.93040 |
| 6.64330 | 64.24050 |

# Input Experimental data

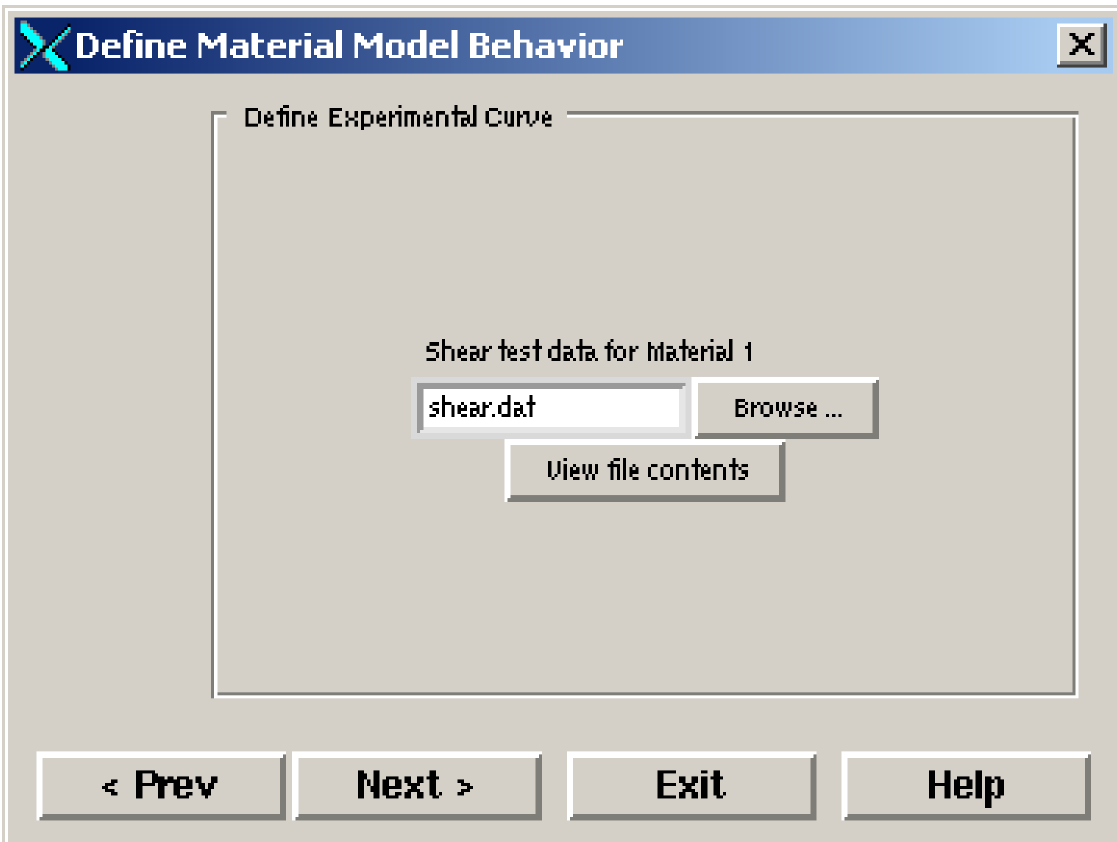
- Input biaxial test data using GUI




- Enter filename that containing biaxial experimental data, and/or click next.
- To skip a test simple click next
- Click view file contents to view the experimental from screen

# Input Experimental data

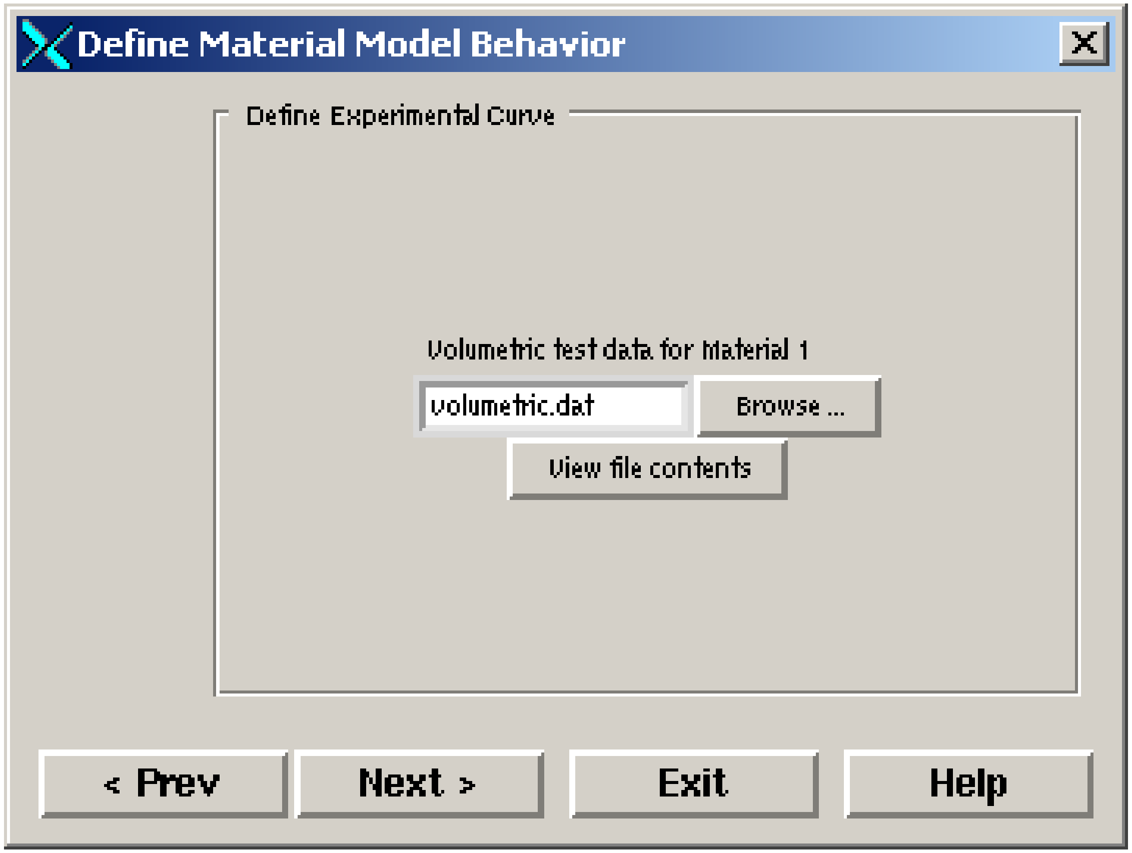
- Input shear test data using GUI




- Enter filename that containing shear experimental data, and/or click next.
- To skip a test simple click next
- Click view file contents to view the experimental from screen

# Input Experimental data

- Input volumetric test data using GUI



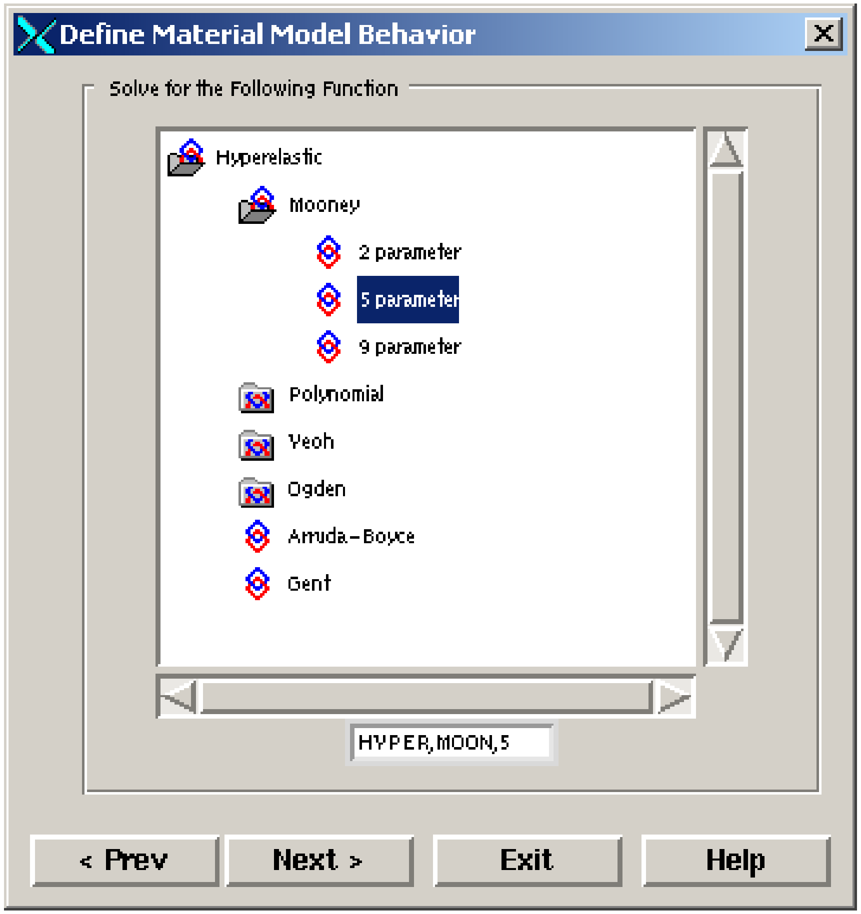

- Enter filename that containing volumetric experimental data, and/or click next.
- To skip a test simple click next
- Click view file contents to view the experimental from screen

# Specify Material Option

- Command for specifying material option
  - TBFT, FADD, ID, option1, option2, option3, option4
  - Option1 = HYPER
  - Option2 = MOON, POLY, OGDE, BOYCE, GENT, YEOH
  - Option3 = 2, 5, 9 for Option2=MOON; 1,2,3, or n for POLY, OGDE, YEOH
- Command for nonlinear curve fitting
  - TBFT, SET, ID, option1, option2, option3, option4, option5
  - Option1 = HYPER
  - Option2 = OGDE, BOYCE, GENT
  - Option3 = 1,2,3, or n for OGDE
  - Option4 = index of coefficient
  - Option5 = initial value of coefficient

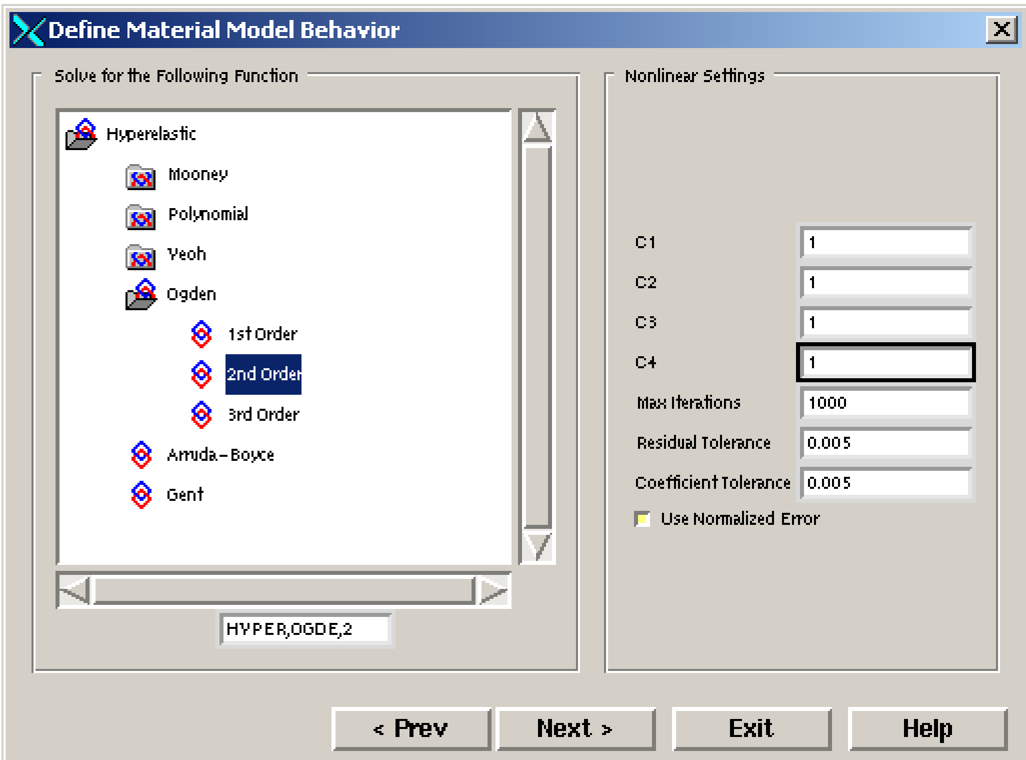
# Specify Material Option

- Specify hyperelastic material option from the GUI tree



# Specify Material Option

- Specify hyperelastic material option from the GUI tree



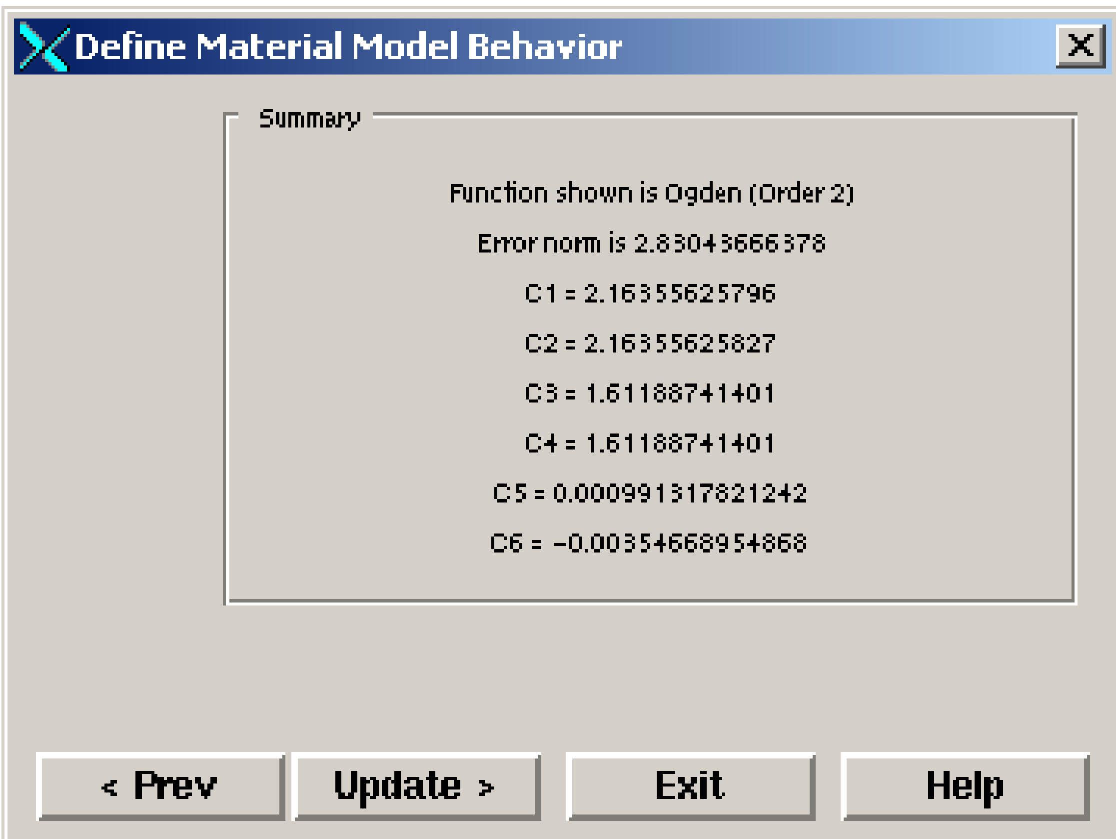

- For Ogden, Arruda-Boyce, Gent a nonlinear curve fitting procedure is used.
- Specify the initial value of coefficients of the chosen models.
- Specify other parameters such as maximum iteration number, tolerance for residual and coefficients

# Data Fitting

- Command for solving the coefficients
  - TBFT, SOLVE, ID, option1, option2, option3, option4,…,Option7
  - Option1 = HYPER
  - Option2 = MOON, POLY, OGDE, BOYCE, GENT, YEOH
  - Option3 = 2, 5, 9 for Option2=MOON; 1,2,3, or n for POLY, OGDE, YEOH
  - Option4 = 0 – unnormalized least squares,
    1 – normalized least squares
  - Option5 = maximum number of iterations
  - Option6 = tolerance of residual changes
  - Option7 = tolerance of coefficient changes

# Data Fitting

- Curve fitting summary

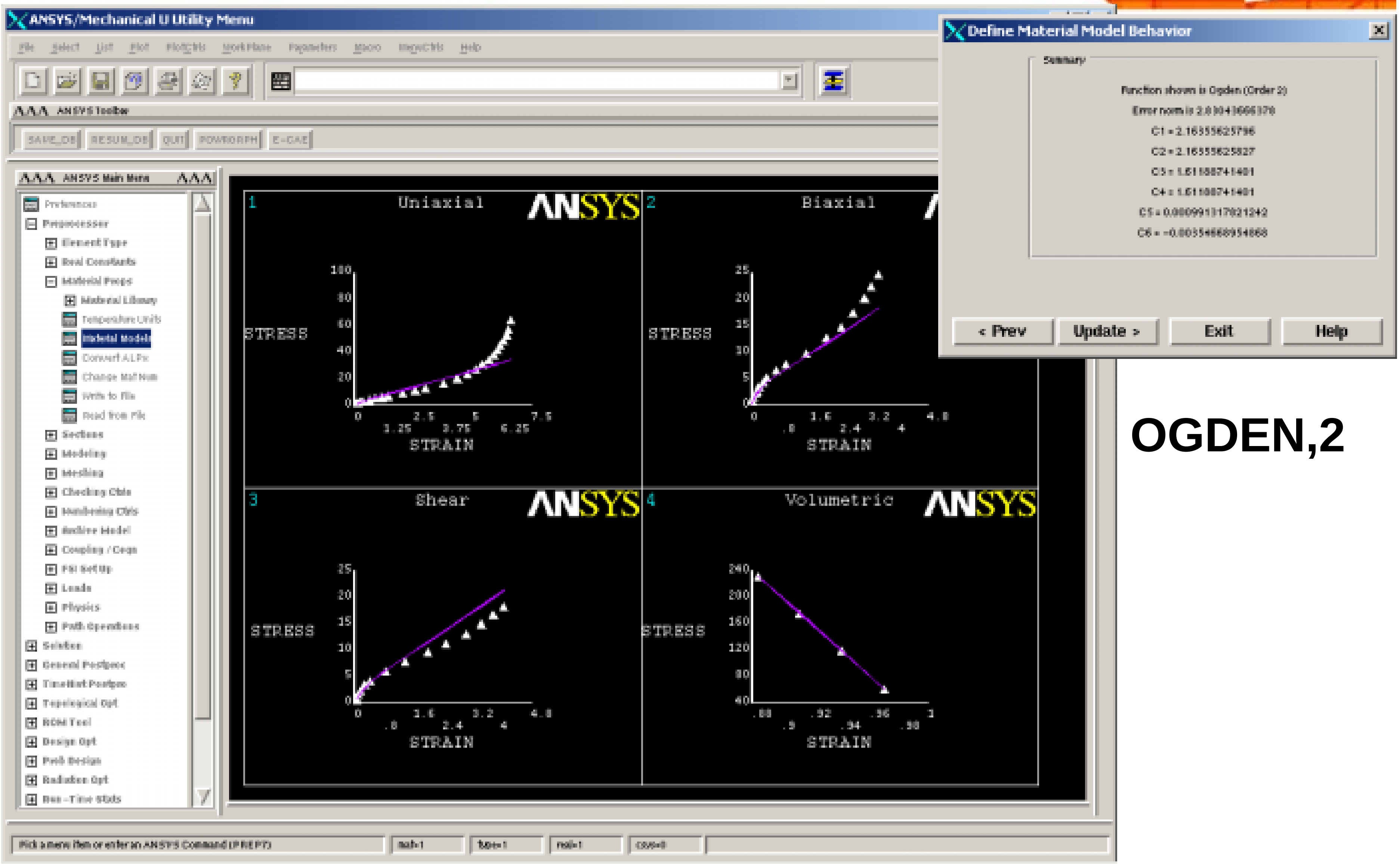



- The coefficients and the error norms are shown in the summary window.
- The graphics plot of curve fitting results are shown in ANSYS standard window.
- Click update to update the coefficients to ANSYS database.

# Curve Plotting

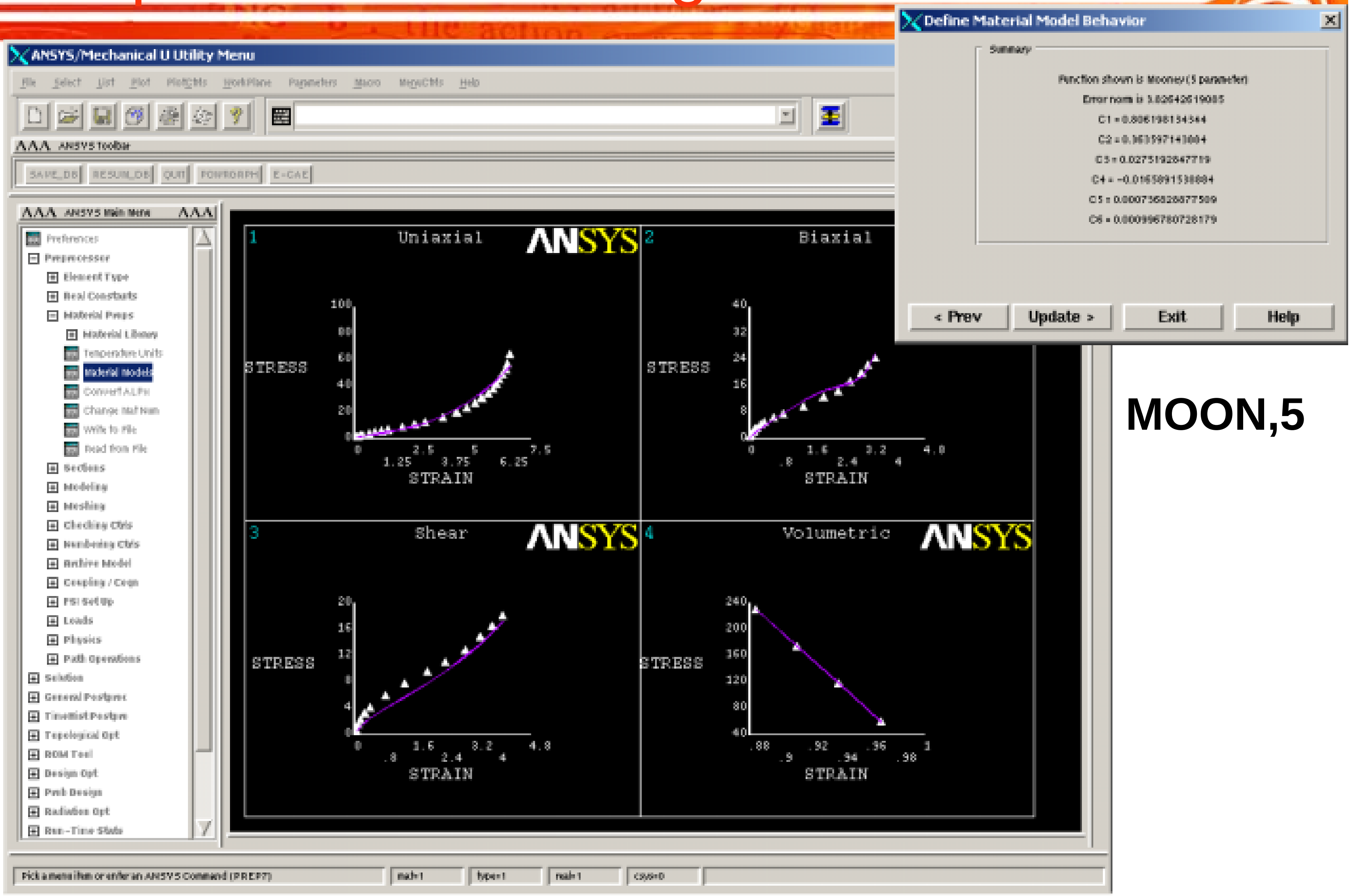
- Command for plotting curves
  - TBFT, PLOT, ID, option1, option2, option3, option4,…,Option7
  - Option1 = UNIA, BIAX, SHEA, VOLU
  - Option2 = HYPER
  - Option3 = MOON, POLY, OGDE, BOYCE, GENT, YEOH
  - Option4 = 2, 5, 9 for Option2=MOON; 1,2,3, or n for POLY, OGDE, YEOH

# Graphics Plot of Fitting curves



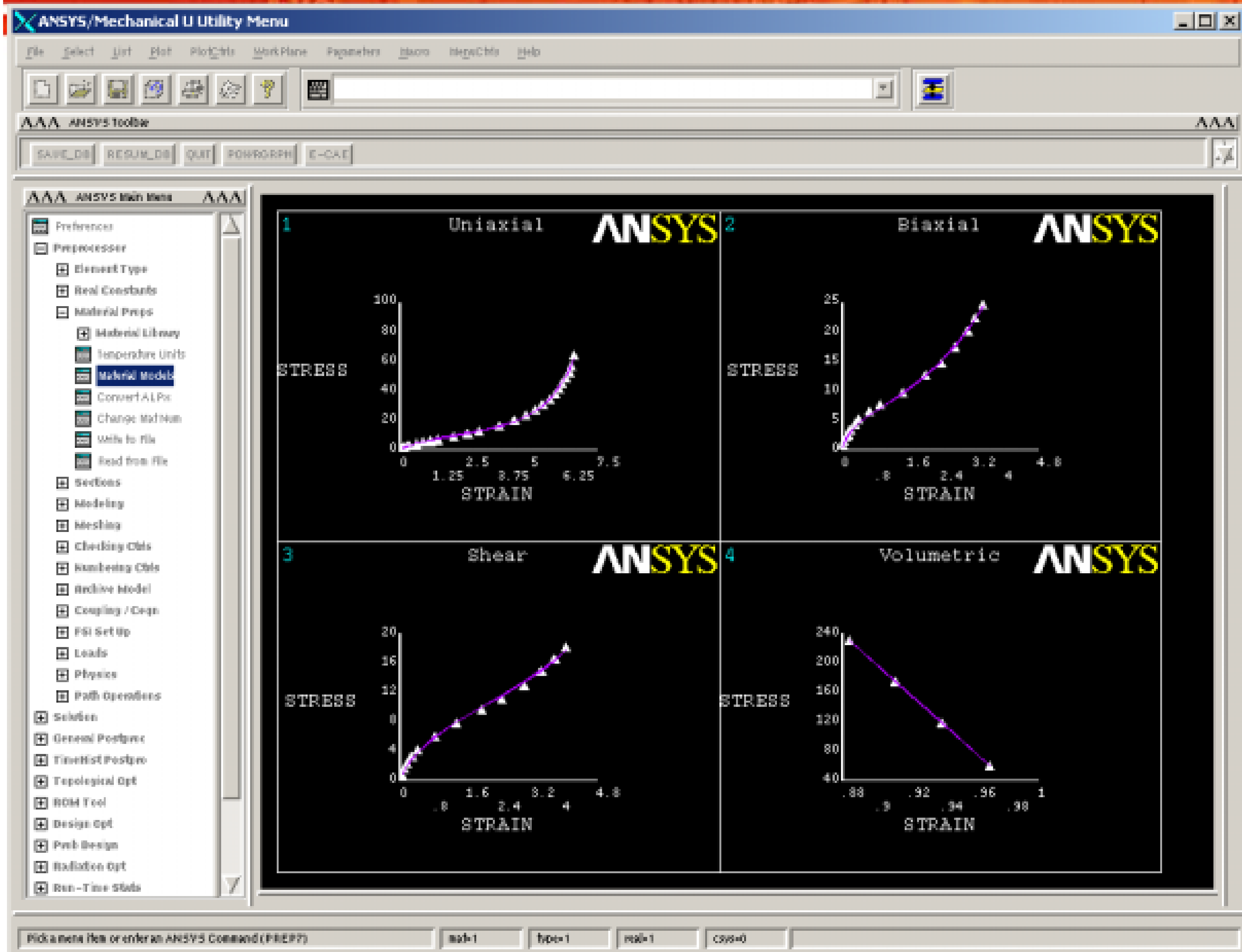

**OGDEN,2**

# Graphics Plot of Fitting curves




**MOON,5**

# Graphics Plot of Fitting curves



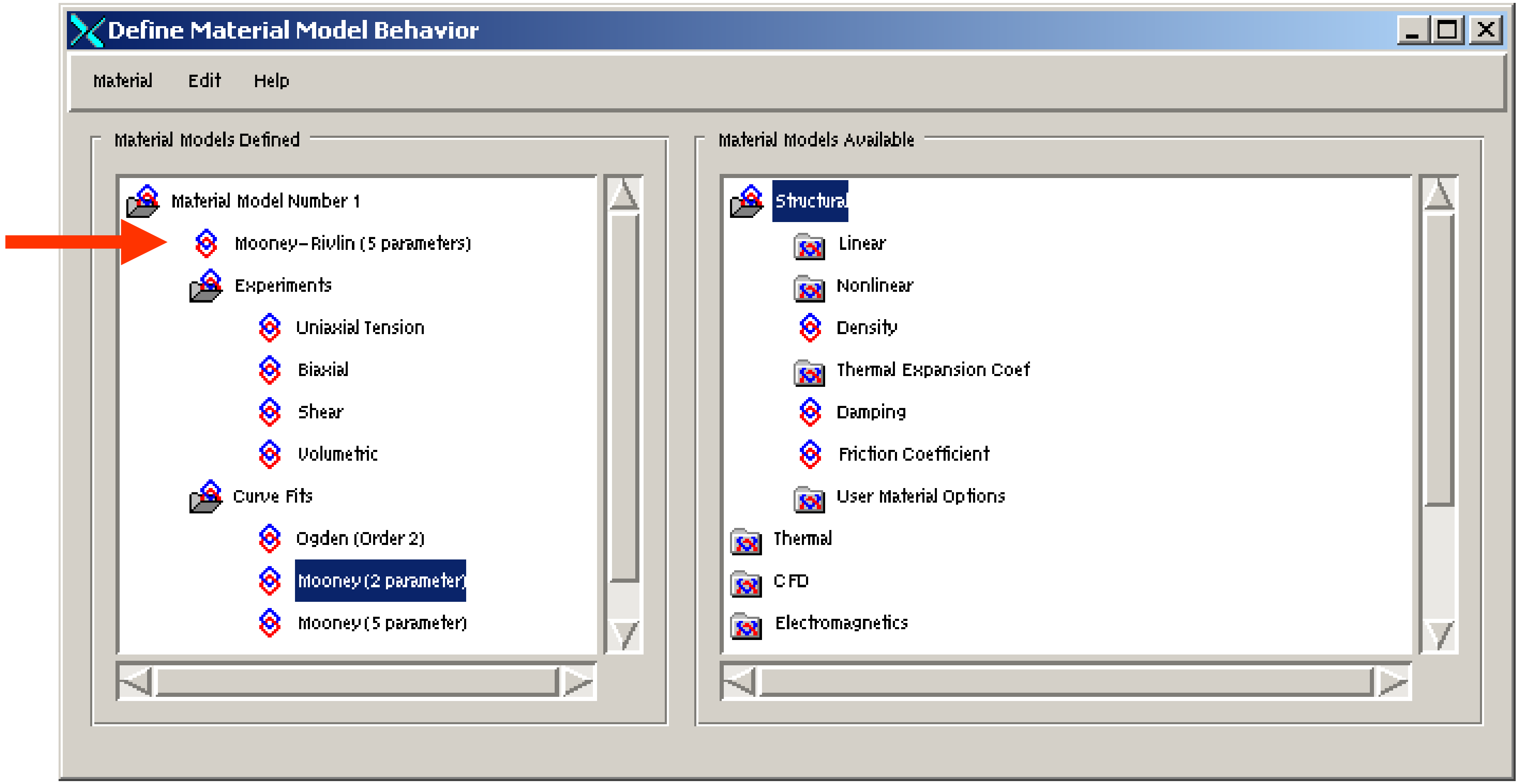

**OGDE,3**

# Data Fitting

- Command for updating results to ANSYS database
  - TBFT, FSET, ID, option1, option2, option3
  - Option1 = HYPER
  - Option2 = MOON, POLY, OGDE, BOYCE, GENT, YEOH
  - Option3 = 2, 5, 9 for Option2=MOON; 1,2,3, or n for POLY, OGDE, YEOH

# Data Fitting

- Update coefficients to ANSYS database




**After update, the hyperelastic option appears in the right hand side of GUI**

# ANSYS Log file

- The commands are written to log file