Created in COMSOL Multiphysics 6.3

Concrete Damage–Plasticity Material Tests

Introduction

This example shows the behavior of the coupled damage–plasticity model for concrete when subjected to different loading conditions. Several material tests that are commonly used to characterize concrete are set up for this purpose

For details on the coupled damage–plasticity material model, see the section *Coupled Damage–Plasticity* in the *Structural Mechanics Module User's Guide*, and Ref. 1 and Ref. 2.

Model Definition

The **Test material** feature is used to test the material model when subjected to different loading conditions. Hence no specific geometry is required for the base component of the model. Concrete is, however, a so-called quasibrittle material which means that its response is size dependent, especially in tension. The size of the test specimen used by **Test material** is therefore important for the tests to give representative results. Here a characteristic size of 0.1 m is used.

In total six different tests are set up:

1. Uniaxial compression
2. Uniaxial tension
3. Biaxial compression, with a biaxiality ratio of 0.5
4. Isotropic (triaxial) compression
5. Uniaxial cyclic loading (tension to compression to tension)
6. Uniaxial cyclic loading (compression to tension)

A generic set of material proprieties are used for the concrete, (see Table 1), but the model can be used to verify the model response for other properties as well. Note that these material properties are sufficient to define the model parameters of the coupled damage–plasticity model, but there are many more parameters available to modify the response of the material model that are here kept equal to their default value.

TABLE 1: MATERIAL PROPERTIES OF THE CONCRETE.

Material property	Symbol	Value
Young's modulus	E	25 GPa
Poisson's ratio	ν	0.2
Compressive strength	σ_{uc}	20 MPa

TABLE 1: MATERIAL PROPERTIES OF THE CONCRETE.

Material property	Symbol	Value
Tensile strength	σ_{ut}	2 MPa
Fracture energy	G_{ft}	100 J/m^2

Results and Discussion

Figure 1 shows the results of the first two tests. The characteristic anisotropy of concrete in compression versus tension is clearly observable.

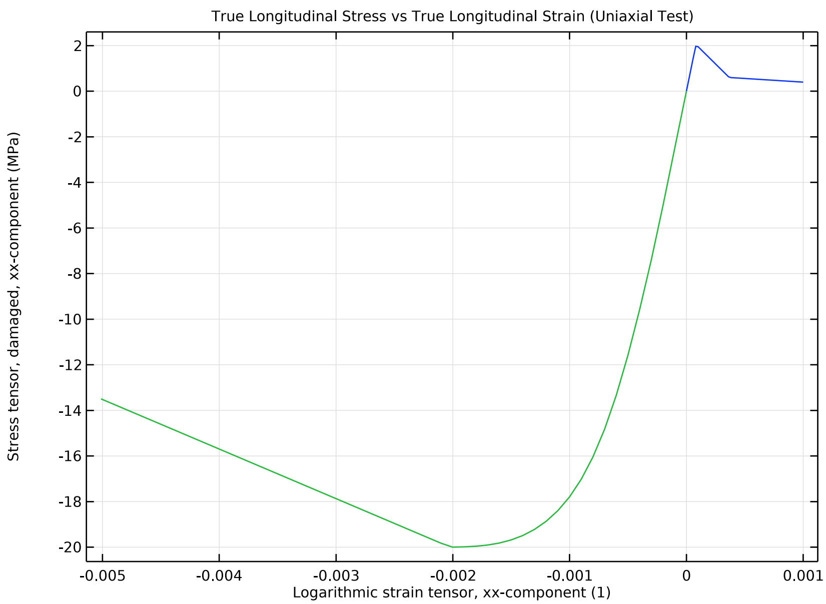

Figure 1: Stress versus strain for concrete subjected to monotonic uniaxial loading.

Results from the biaxial compression test are shown in Figure 2, which shows the stress in the main loading direction versus all three normal components of the strain tensor.

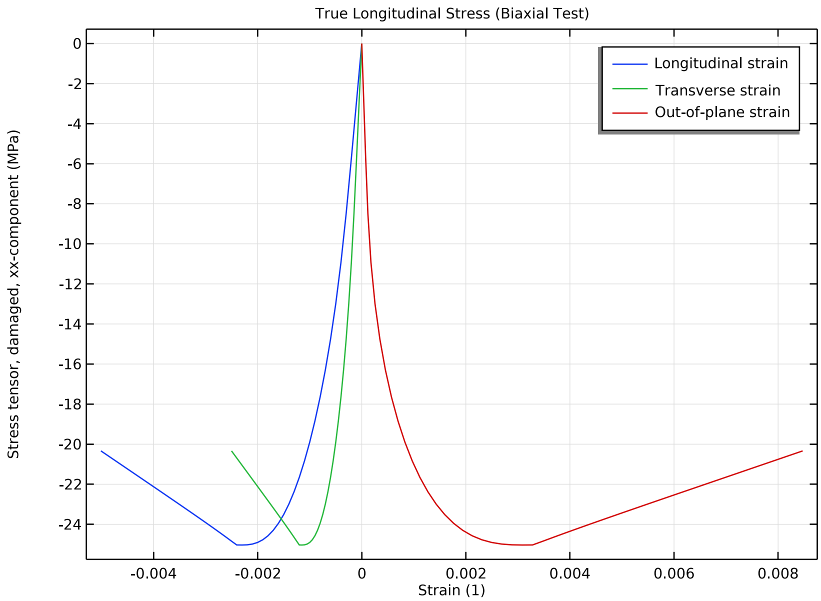

Figure 2: Stress versus strain for concrete subjected to monotonic biaxial compression.

Results from the isotropic compression test are shown in Figure 3, where it is clearly visible that the model response is ductile. The transition from a quasibrittle to a ductile response as the stress state goes toward isotropic compression is an important characteristic of concrete subjected to severe loading.

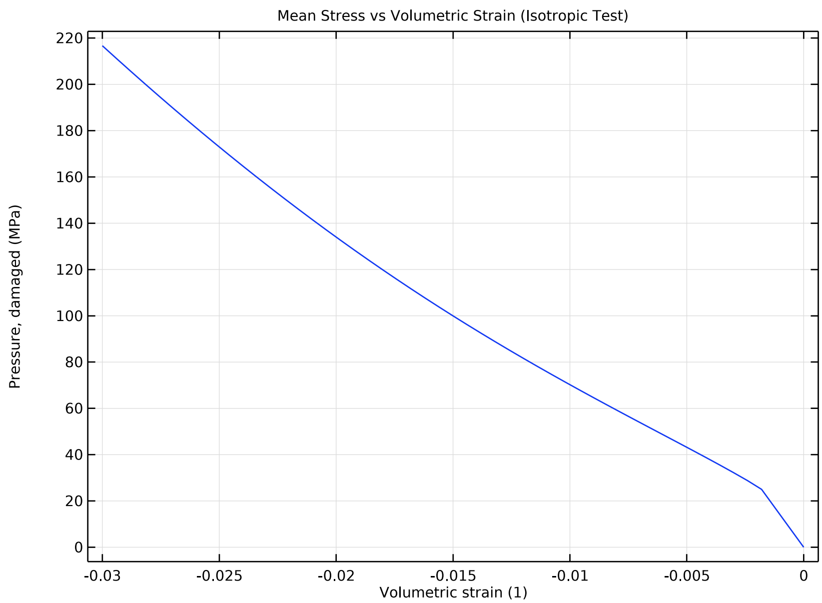

Figure 3: Stress versus strain for concrete subjected to monotonic isotropic compression.

Figure 4 and Figure 5 show results from the two cyclic tests. It is clearly visible how the response during cyclic loading deviates from the monotonic stress versus strain curve since there is irreversible deformation. In Figure 4 one can also note that all available plastic deformation occurs when the specimen is loaded in tension and starts to crack. Hence, there is no plastic hardening when the stress is reversed to compression; instead the response is “elastic” until softening starts.

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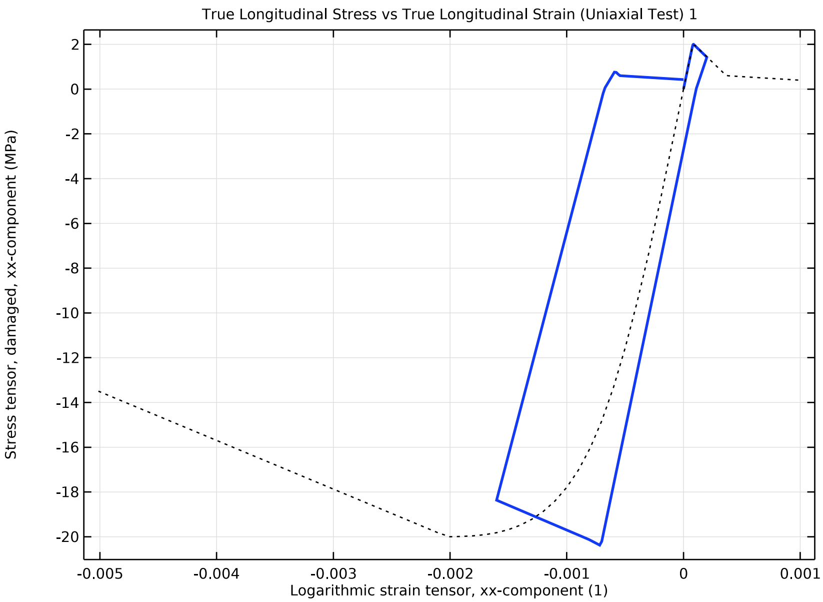

Figure 4: Stress versus strain for concrete subjected to cyclic uniaxial loading going tension to compression and back to tension. The dotted black curve shows the stress versus strain for monotonic loading.

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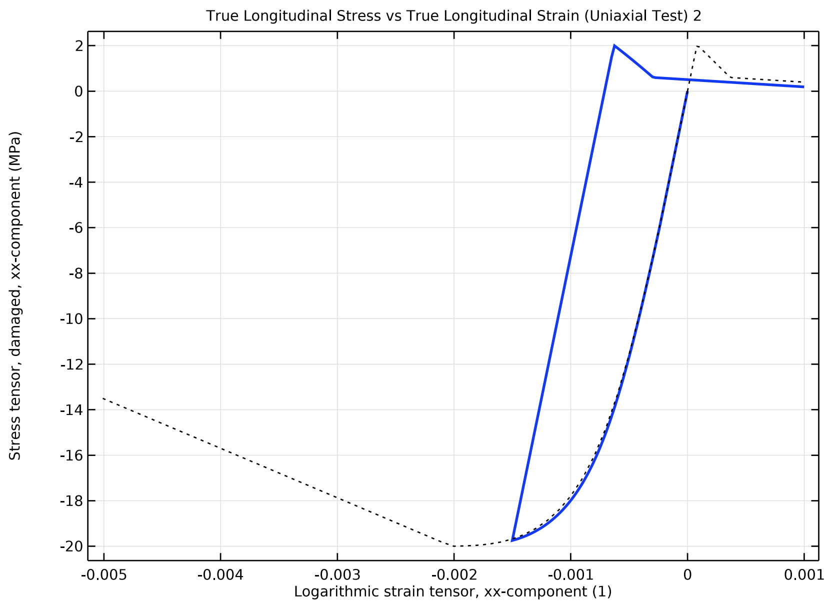

Figure 5: Stress versus strain for concrete subjected to cyclic uniaxial loading going from compression to tension. The dotted black curve shows the stress versus strain for monotonic loading.

References

1. P. Grassl and M. Jirásek, "Damage-plastic model for concrete failure," *Int. J. Solids Struct.*, vol. 43, pp. 7166–7196, 2006.

2. P. Grassl, D. Xenos, U. Nyström, R. Rempling, and K. Gylltoft, "CDPM2: A damage-plasticity approach to modelling the failure of concrete," *Int. J. Solids Struct.*, vol. 50, pp. 3805–3816, 2013.

Application Library path: `Geomechanics_Module/Verification_Examples/concrete_damage_plasticity`

Modeling Instructions

From the **File** menu, choose **New**.

NEW

In the **New** window, click **Model Wizard**.

MODEL WIZARD

1 In the **Model Wizard** window, click **3D**.

2 In the **Select Physics** tree, select **Structural Mechanics** > **Solid Mechanics (solid)**.

3 Click **Add**.

4 Click **Done**.

GEOMETRY 1

Block 1 (blk1)

In the **Geometry** toolbar, click **Block**.

SOLID MECHANICS (SOLID)

Linear Elastic Material 1

In the **Model Builder** window, under **Component 1 (comp1)** > **Solid Mechanics (solid)** click **Linear Elastic Material 1**.

Concrete 1

1 In the **Physics** toolbar, click **Attributes** and choose **Concrete**.

2 In the **Settings** window for **Concrete**, locate the **Concrete Model** section.

3 From the **Material model** list, choose **Coupled damage–plasticity**.

ADD MATERIAL

1 In the **Materials** toolbar, click **Add Material** to open the **Add Material** window.

2 Go to the **Add Material** window.

3 In the tree, select **Built-in** > **Concrete**.

4 Click the **Add to Component** button in the window toolbar.

5 In the **Materials** toolbar, click **Add Material** to close the **Add Material** window.

MATERIALS

Concrete (mat1)

1 In the **Settings** window for **Material**, locate the **Material Contents** section.

2 In the table, enter the following settings:

Property	Variable	Value	Unit	Property group
Tensile strength	sigmaut	2[MPa]	Pa	Yield stress parameters
Compressive strength	sigmauc	20[MPa]	Pa	Yield stress parameters
Tensile fracture energy	Gft	100[J/m^2]	J/m²	Fracture parameters

Add a number of monotonic tests for different loading conditions.

SOLID MECHANICS (SOLID)

Monotonic Tests

1 In the **Physics** toolbar, click **Global** and choose **Test Material**.

2 In the **Settings** window for **Test Material**, type `Monotonic Tests` in the **Label** text field.

3 Select Domain 1 only.

4 Locate the **Material Tests** section. From the **Specimen size** list, choose **User defined**.

5 In the L text field, type `0.1[m]`.

6 Find the **Tests** subsection. In the λ_{min} text field, type `1-5e-3`.

7 In the λ_{max} text field, type `1+1e-3`.

8 Select the **Biaxial test** checkbox.

9 In the λ_{min} text field, type `1-5e-3`.

10 In the λ_{max} text field, type `1`.

11 In the β text field, type `0.5`.

12 Select the **Isotropic test** checkbox.

13 In the λ_{min} text field, type `1-1e-2`.

14 Click **Automated Model Setup** in the upper-right corner of the **Material Tests** section. From the menu, choose **Set up and Run Tests**.

Set default units for result presentation.

RESULTS

Preferred Units 1

1 In the **Results** toolbar, click **Configurations** and choose **Preferred Units**.

2 In the **Settings** window for **Preferred Units**, locate the **Units** section.

3 Click **Add Physical Quantity**.

4 In the **Physical Quantity** dialog, select **Solid Mechanics** > **Stress tensor (N/m^2)** in the tree.

5 Click **OK**.

6 In the **Settings** window for **Preferred Units**, locate the **Units** section.

7 In the table, enter the following settings:

Quantity	Unit	Preferred unit
Stress tensor	N/m^2	MPa

8 Click **Add Physical Quantity**.

9 In the **Physical Quantity** dialog, select **General** > **Pressure (Pa)** in the tree.

10 Click **OK**.

11 In the **Settings** window for **Preferred Units**, locate the **Units** section.

12 In the table, enter the following settings:

Quantity	Unit	Preferred unit
Pressure	Pa	MPa

13 Click **Apply**.

14 In the **Model Builder** window, expand the **Results** node.

True Longitudinal Stress vs True Longitudinal Strain (Uniaxial Test)

In the **Model Builder** window, expand the **Results** > **Material Tests (Study: Monotonic Tests)** node.

Point Graph 2

1 In the **Model Builder** window, expand the **True Longitudinal Stress vs True Longitudinal Strain (Uniaxial Test)** node, then click **Point Graph 2**.

2 In the **True Longitudinal Stress vs True Longitudinal Strain (Uniaxial Test)** toolbar, click **Plot**.

Point Graph 1

1 In the **Model Builder** window, expand the **Results** > **Material Tests (Study: Monotonic Tests)** > **True Longitudinal Stress vs True Longitudinal Strain (Biaxial Test)** node, then click **Point Graph 1**.

2 In the **Settings** window for **Point Graph**, click to expand the **Legends** section.
3 Select the **Show legends** checkbox.
4 From the **Legends** list, choose **Manual**.
5 In the table, enter the following settings:

Legends
`Longitudinal strain`

Also plot the longitudinal stress versus the transverse and out-of-plane strain components.

Point Graph 2

1 Right-click **Results** > **Material Tests (Study: Monotonic Tests)** > **True Longitudinal Stress vs True Longitudinal Strain (Biaxial Test)** > **Point Graph 1** and choose **Duplicate**.
2 In the **Settings** window for **Point Graph**, locate the **x-Axis Data** section.
3 In the **Expression** text field, type `solid1.elogyy`.
4 Locate the **Legends** section. In the table, enter the following settings:

Legends
`Transverse strain`

Point Graph 3

1 Right-click **Point Graph 2** and choose **Duplicate**.
2 In the **Settings** window for **Point Graph**, locate the **x-Axis Data** section.
3 In the **Expression** text field, type `solid1.elogzz`.
4 Locate the **Legends** section. In the table, enter the following settings:

Legends
`Out-of-plane strain`

True Longitudinal Stress (Biaxial Test)

1 In the **Model Builder** window, under **Results** > **Material Tests (Study: Monotonic Tests)** click **True Longitudinal Stress vs True Longitudinal Strain (Biaxial Test)**.
2 In the **Settings** window for **1D Plot Group**, type `True Longitudinal Stress (Biaxial Test)` in the **Label** text field.
3 Locate the **Plot Settings** section.
4 Select the **x-axis label** checkbox. In the associated text field, type `Strain (1)`.

5 In the **True Longitudinal Stress (Biaxial Test)** toolbar, click **Plot**.

Point Graph 1

1 In the **Model Builder** window, expand the **Mean Stress vs Volumetric Strain (Isotropic Test)** node, then click **Point Graph 1**.

2 In the **Mean Stress vs Volumetric Strain (Isotropic Test)** toolbar, click **Plot**.

Add a cyclic uniaxial test for the loading sequence: tension to compression to tension.

GLOBAL DEFINITIONS

Interpolation 1 (int1)

1 In the **Home** toolbar, click f(X) **Functions** and choose **Global** > **Interpolation**.

2 In the **Settings** window for **Interpolation**, locate the **Definition** section.

3 In the table, enter the following settings:

t	f(t)
0	0
1	2e-4
2	-1.6e-3
3	0

SOLID MECHANICS (SOLID)

Cyclic Test 1

1 In the **Physics** toolbar, click **Global** and choose **Test Material**.

2 In the **Settings** window for **Test Material**, type `Cyclic Test 1` in the **Label** text field.

3 Select Domain 1 only.

4 Locate the **Material Tests** section. From the **Specimen size** list, choose **User defined**.

5 In the L text field, type `0.1[m]`.

6 From the **Test setup** list, choose **User defined**.

7 In the $\mathrm{para}_{\max}$ text field, type `3`.

8 In the N_p text field, type `300`.

9 Find the **Tests** subsection. In the λ text field, type `1+int1(para)`.

10 Click **Automated Model Setup** in the upper-right corner of the **Material Tests** section. From the menu, choose **Set up and Run Tests**.

Add the uniaxial stress-strain curve from the monotonic test as a reference.

Results

Point Graph 1, Point Graph 2

1 In the **Model Builder** window, under **Results** > **Material Tests (Study: Monotonic Tests)** > **True Longitudinal Stress vs True Longitudinal Strain (Uniaxial Test)**, Ctrl-click to select **Point Graph 1** and **Point Graph 2**.

2 Right-click and choose **Copy**.

True Longitudinal Stress vs True Longitudinal Strain (Uniaxial Test) 1

1 In the **Model Builder** window, expand the **Results** > **Material Tests (Study: Cyclic Test 1)** node.

2 Right-click **True Longitudinal Stress vs True Longitudinal Strain (Uniaxial Test) 1** and choose **Paste Multiple Items**.

Point Graph 2, Point Graph 3

1 In the **Settings** window for **Point Graph**, click to expand the **Coloring and Style** section.

2 Find the **Line style** subsection. From the **Line** list, choose **Dotted**.

3 From the **Color** list, choose **Black**.

Point Graph 3

1 In the **Model Builder** window, click **Point Graph 3**.

2 In the **Settings** window for **Point Graph**, locate the **Coloring and Style** section.

3 Find the **Line style** subsection. From the **Line** list, choose **Dotted**.

4 From the **Color** list, choose **Black**.

Point Graph 1

1 In the **Model Builder** window, click **Point Graph 1**.

2 In the **Settings** window for **Point Graph**, locate the **Coloring and Style** section.

3 From the **Width** list, choose **2**.

4 In the **True Longitudinal Stress vs True Longitudinal Strain (Uniaxial Test) 1** toolbar, click **Plot**.

Add a cyclic uniaxial test for the loading sequence: compression to tension.

Global Definitions

Interpolation 2 (int2)

1 In the **Home** toolbar, click f(x) **Functions** and choose **Global** > **Interpolation**.

2 In the **Settings** window for **Interpolation**, locate the **Definition** section.

3 In the table, enter the following settings:

t	f(t)
0	0
1	-1.5e-3
2	1e-3

SOLID MECHANICS (SOLID)

Cyclic Test 2

1 In the **Physics** toolbar, click **Global** and choose **Test Material**.

2 In the **Settings** window for **Test Material**, type `Cyclic Test 2` in the **Label** text field.

3 Select Domain 1 only.

4 Locate the **Material Tests** section. From the **Specimen size** list, choose **User defined**.

5 In the L text field, type `0.1[m]`.

6 From the **Test setup** list, choose **User defined**.

7 In the para_{max} text field, type `2`.

8 In the N_p text field, type `200`.

9 Find the **Tests** subsection. In the λ text field, type `1+int2(para)`.

10 Click **Automated Model Setup** in the upper-right corner of the **Material Tests** section. From the menu, choose **Set up and Run Tests**.

RESULTS

Point Graph 2, Point Graph 3

1 In the **Model Builder** window, under **Results** > **Material Tests (Study: Cyclic Test 1)** > **True Longitudinal Stress vs True Longitudinal Strain (Uniaxial Test) 1**, Ctrl-click to select **Point Graph 2** and **Point Graph 3**.

2 Right-click and choose **Copy**.

True Longitudinal Stress vs True Longitudinal Strain (Uniaxial Test) 2

1 In the **Model Builder** window, expand the **Results** > **Material Tests (Study: Cyclic Test 2)** node.

2 Right-click **True Longitudinal Stress vs True Longitudinal Strain (Uniaxial Test) 2** and choose **Paste Multiple Items**.

Point Graph 1

1 In the **Settings** window for **Point Graph**, locate the **Coloring and Style** section.

2 From the **Width** list, choose **2**.

3 In the **True Longitudinal Stress vs True Longitudinal Strain (Uniaxial Test) 2** toolbar, click **Plot**.