

Memorandum



Date: April 5, 2019
To: PFC 6 Documentation Set
From: David Potyondy
Re: Material-Modeling Support for PFC [fistPkg6.5] (Example Materials 2)
Ref: ICG7766-L

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1.0 EXAMPLE MATERIALS

The PFC 6.0 FISHTank produces linear, contact-bonded, parallel-bonded, flat-jointed and user-defined materials. Examples for each material are provided in the Example Materials memos. Each example serves as a base case and provides a material at the lowest resolution sufficient to demonstrate system behavior. There is a material-genesis project for each material, and these projects are in the **fistPkg6.N/ExampleProjects/MatGen-M** directory, where **N** is the version number of the PFC FISHTank, and **M** is the material type. There are separate 2D and 3D projects for each material, and both projects are contained within the same example-project directory. Examples for the parallel-bonded and flat-jointed materials and the interface are provided in the following subsections.¹

¹ The microstructural arrangement and stress-strain curves obtained with the current FISHTank may vary slightly from those shown here, which may have been generated by an earlier version of the FISHTank.

1.1 Parallel-Bonded Material Example

The parallel-bonded material example is in the **MatGen-ParallelBonded** example-project directory. A parallel-bonded material is created to represent a typical sandstone, which we take to be Castlegate sandstone.² We denote our sandstone material as the **SS_ParallelBonded** material with microproperties listed in Table 1. The material is created in a cubic material vessel (of 50 mm side length, with a 3 GPa effective modulus).³ The grain-scaling packing procedure is used to pack the grains to a 30 MPa material pressure, and then parallel bonds are added between all grains that are in contact with one another (see Figure 1). The material is then subjected to compression, diametral-compression and direct-tension tests. The test results can be displayed and interpreted in the same way as for the contact-bonded material example in the Example Materials 1 memo.

Table 1 Microproperties of SS_ParallelBonded Material*

Property	Value
Common group:	
N_m	SS_ParallelBonded
$T_m, \alpha, C_p, \rho_v [\text{kg/m}^3]$	2, 0.7, 1, 1960
$S_g, T_{SD}, \{D_{\{l,u\}} [\text{mm}], \phi\}, D_{mult}$	0, 0, {4.0,6.0,1.0}, 1.0
Packing group:	
$S_{RN}, P_m [\text{MPa}], \varepsilon_p, \varepsilon_{lim}, n_{lim}$	10000, 30, 1×10^{-2} , 8×10^{-3} , 2×10^6
C_p, n_c	1, 0.30
Parallel-bonded material group:	
Linear group:	
$E^* [\text{GPa}], \kappa^*, \mu$	1.5, 1.5, 0.4
Parallel-bond group:	
$g_i [\text{mm}], \bar{\lambda}, \bar{E}^* [\text{GPa}], \bar{\kappa}^*, \bar{\beta}$	0, 1.0, 1.5, 1.5, 1.0
$(\bar{\sigma}_c)_{\{m, sd\}} [\text{MPa}], (\bar{c})_{\{m, sd\}} [\text{MPa}], \bar{\phi} [\text{degrees}]$	{1.0,0}, {20.0,0}, 0
Linear material group:	
$E_n^* [\text{GPa}], \kappa_n^*, \mu_n$	1.5, 1.5, 0.4

* Parallel-bonded material parameters are defined in Table 4 of the base memo.

² Typical properties of Castlegate sandstone are listed in footnote 4 of the Example Materials 1 memo.

³ A parallel-bonded clumped material can be created in the same way as for the contact-bonded material example.

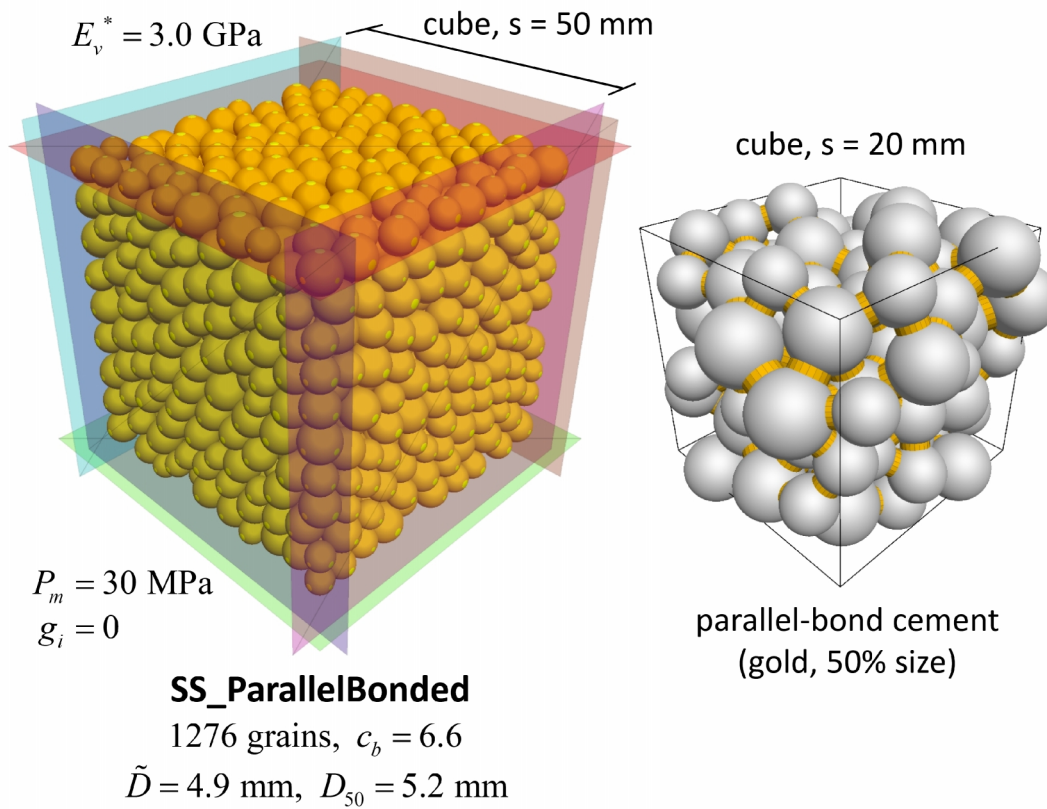


Figure 1 *SS_ParallelBonded material at the end of material genesis with grains and intact parallel bonds in the microstructural box.*

1.2 Parallel-Bonded Material Example (2D model)

The parallel-bonded material example for the 2D model is in the **MatGen-ParallelBonded** example-project directory. The files for the 2D model contain the **p2*** extension (e.g., **MatGen.p2prj** and **mpParams.p2dat**). A 2D parallel-bonded material (consisting of rigid unit-thickness disks) is created to represent a typical sandstone, which we take to be Castlegate sandstone.⁴ We denote our sandstone material as the **SS_ParallelBonded2D** material with microproperties listed in Table 2. The material is created in a square-cuboid material vessel (of 50 mm side length and unit depth, with a 3 GPa effective modulus).⁵ The grain-scaling packing procedure is used to pack the grains to a 30 MPa material pressure, and then parallel bonds are added between all grains that are in contact with one another (see Figure 2). The material is then subjected to compression, diametral-compression and direct-tension tests. The test results can be displayed and interpreted in the same way as for the contact-bonded material example in the Example Materials 1 memo.

Table 2 Microproperties of SS_ParallelBonded2D Material*

Property	Value
Common group:	
N_m	SS_ParallelBonded2D
$T_m, \alpha, C_p, \rho_v [\text{kg/m}^3]$	2, 0.7, 1, 1960
$S_g, T_{SD}, \{D_{\{l,u\}} [\text{mm}], \phi\}, D_{mult}$	0, 0, {4.0,6.0,1.0}, 1.0
Packing group:	
$S_{RN}, P_m [\text{MPa}], \varepsilon_p, \varepsilon_{lim}, n_{lim}$	10000, 30, 1×10^{-2} , 8×10^{-3} , 2×10^6
C_p, n_c	1, 0.08
Parallel-bonded material group:	
Linear group:	
$E^* [\text{GPa}], \kappa^*, \mu$	1.5, 1.5, 0.4
Parallel-bond group:	
$g_i [\text{mm}], \bar{\lambda}, \bar{E}^* [\text{GPa}], \bar{\kappa}^*, \bar{\beta}$	0, 1.0, 1.5, 1.5, 1.0
$(\bar{\sigma}_c)_{\{m, sd\}} [\text{MPa}], (\bar{c})_{\{m, sd\}} [\text{MPa}], \bar{\phi} [\text{degrees}]$	{1.0,0}, {20.0,0}, 0
Linear material group:	
$E_n^* [\text{GPa}], \kappa_n^*, \mu_n$	1.5, 1.5, 0.4

* Parallel-bonded material parameters are defined in Table 4 of the base memo.

⁴ Typical properties of Castlegate sandstone are listed in footnote 4 of the Example Materials 1 memo.

⁵ A 2D parallel-bonded clumped material can be created in the same way as for the 2D contact-bonded material example.

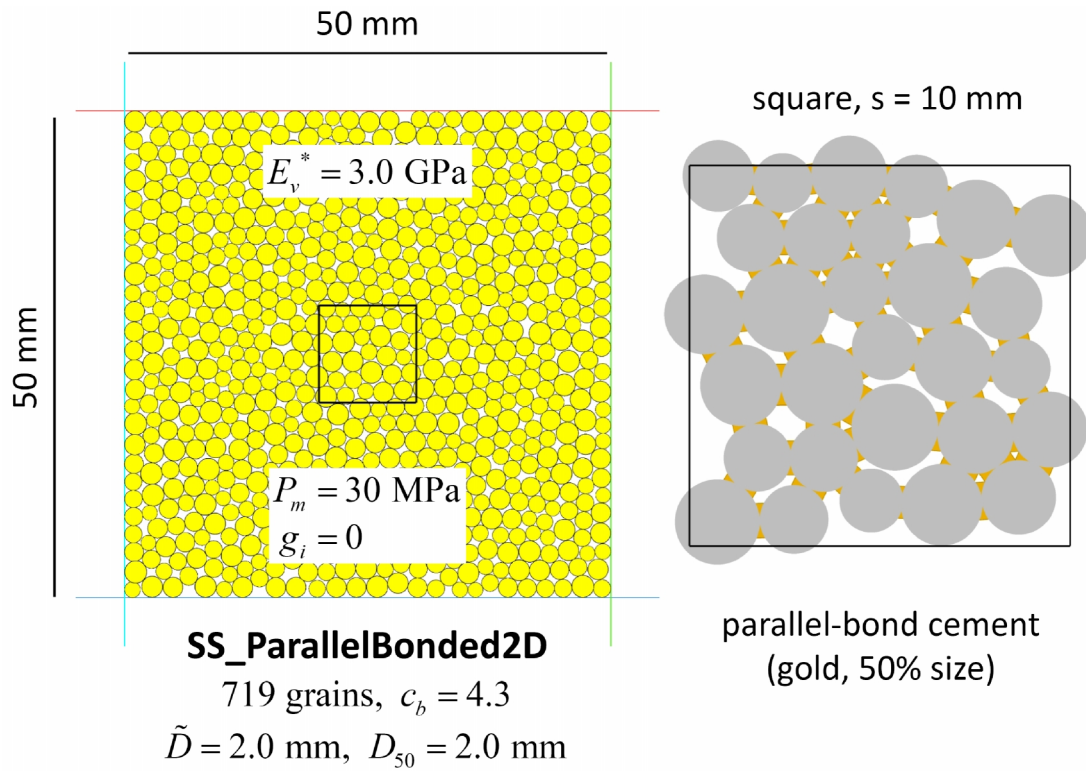


Figure 2 *SS_ParallelBonded2D material at the end of material genesis with grains and intact parallel bonds in the microstructural box.*

1.3 Flat-Jointed Material Example

The flat-jointed material example is in the **MatGen-FlatJointed** example-project directory. A flat-jointed material is created to represent a typical sandstone, which we take to be Castlegate sandstone.⁶ We denote our sandstone material as the SS_FlatJointed material with microproperties listed in Table 3. The material is created in a cubic material vessel (of 50 mm side length, with a 3 GPa effective modulus).⁷ The grain-scaling packing procedure is used to pack the grains to a 30 MPa material pressure, and then the flat-joint contact model is installed between all grains that are in contact with one another and the flat-jointed material properties are assigned to those flat-jointed contacts (see Figure 3). The material is then subjected to compression, diametral-compression and direct-tension tests. The test results can be displayed and interpreted in the same way as for the contact-bonded material example in the Example Materials 1 memo.

Table 3 Microproperties of SS_FlatJointed Material*

Property	Value
Common group:	
N_m	SS_FlatJointed
$T_m, \alpha, C_p, \rho_v [\text{kg/m}^3]$	3, 0.7, 1, 1960
$S_g, T_{SD}, \{D_{\{l,u\}} [\text{mm}], \phi\}, D_{mult}$	0, 0, {4.0,6.0,1.0}, 1.0
Packing group:	
$S_{RN}, P_m [\text{MPa}], \varepsilon_p, \varepsilon_{lim}, n_{lim}$	10000, 30, 1×10^{-2} , 8×10^{-3} , 2×10^6
C_p, n_c	1, 0.30
Flat-jointed material group:	
$C_{MS}, g_i [\text{mm}], \phi_B, \phi_G, (g_o)_{\{m, sd\}} [\text{mm}], \{N_r, N_\alpha\}$	false, 0, 1, 0, {0,0}, {1,3}
$\{C_\lambda, \lambda_v\}, E^* [\text{GPa}], \kappa^*, \mu$	{0, 1.0}, 3.0, 1.5, 0.4
$(\sigma_c)_{\{m, sd\}} [\text{MPa}], (c)_{\{m, sd\}} [\text{MPa}], \phi [\text{degrees}]$	{1.0,0}, {20.0,0}, 0
Linear material group:	
$E_n^* [\text{GPa}], \kappa_n^*, \mu_n$	1.5, 1.5, 0.4

* Flat-jointed material parameters are defined in Table 5 of the base memo.

⁶ Typical properties of Castlegate sandstone are listed in footnote 4 of the Example Materials 1 memo.

⁷ A flat-jointed clumped material can be created in the same way as for the contact-bonded material example.

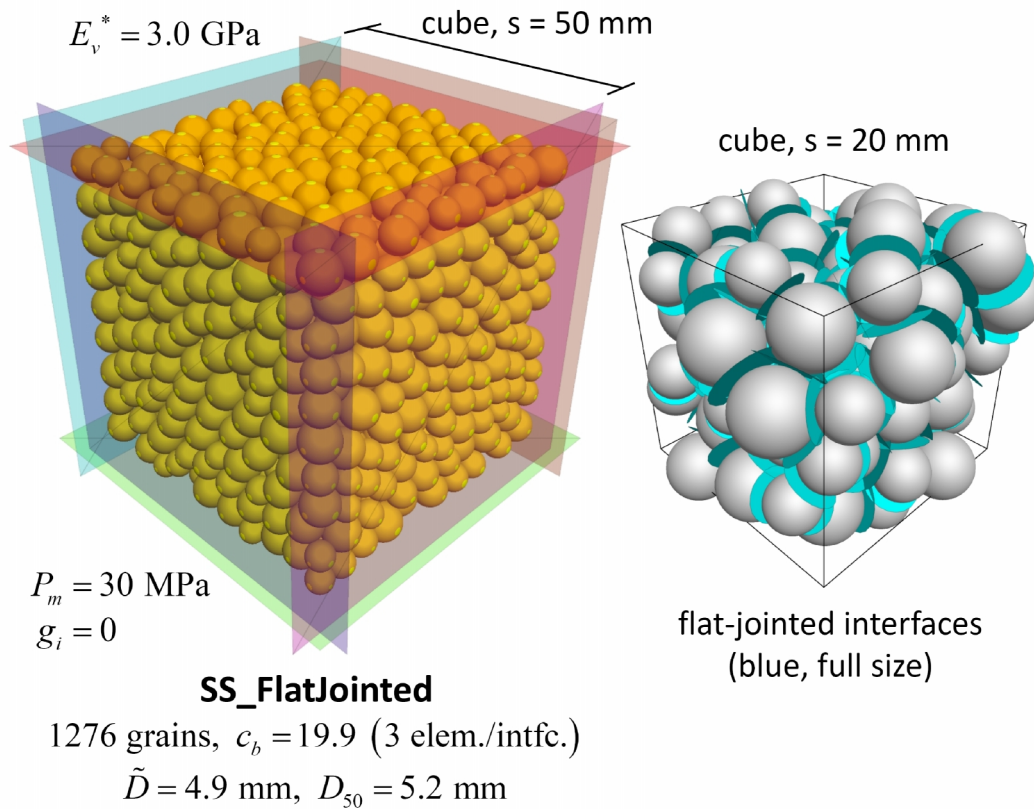


Figure 3 *SS_FlatJointed material at the end of material genesis with grains and flat-jointed interfaces in the microstructural box.*

1.4 Flat-Jointed Material Example (2D model)

The flat-jointed material example for the 2D model is in the **MatGen-FlatJointed** example-project directory. The files for the 2D model contain the **p2*** extension (e.g., **MatGen.p2prj** and **mpParams.p2dat**). A 2D flat-jointed material (consisting of rigid unit-thickness disks) is created to represent a typical sandstone, which we take to be Castlegate sandstone.⁸ We denote our sandstone material as the **SS_FlatJointed2D** material with microproperties listed in Table 4. The material is created in a square-cuboid material vessel (of 50 mm side length and unit depth, with a 3 GPa effective modulus).⁹ The grain-scaling packing procedure is used to pack the grains to a 30 MPa material pressure, and then the flat-joint contact model is installed between all grains that are in contact with one another and the flat-jointed material properties are assigned to those flat-jointed contacts (see Figure 4). The material is then subjected to compression, diametral-compression and direct-tension tests. The test results can be displayed and interpreted in the same way as for the contact-bonded material example in the Example Materials 1 memo.

Table 4 Microproperties of SS_FlatJointed2D Material*

Property	Value
Common group:	
N_m	SS_FlatJointed2D
$T_m, \alpha, C_\rho, \rho_v [\text{kg/m}^3]$	3, 0.7, 1, 1960
$S_g, T_{SD}, \{D_{\{l,u\}} [\text{mm}], \phi\}, D_{mult}$	0, 0, {1.6,2.4,1.0}, 1.0
Packing group:	
$S_{RN}, P_m [\text{MPa}], \varepsilon_p, \varepsilon_{lim}, n_{lim}$	10000, 30, 1×10^{-2} , 8×10^{-3} , 2×10^6
C_p, n_c	1, 0.08
Flat-jointed material group:	
$C_{MS}, g_i [\text{mm}], \phi_B, \phi_G, (g_o)_{\{m, sd\}} [\text{mm}], N_r$	false, 0, 1, 0, {0,0}, 2
$\{C_\lambda, \lambda_v\}, E^* [\text{GPa}], \kappa^*, \mu$	{0, 1.0}, 3.0, 1.5, 0.4
$(\sigma_c)_{\{m, sd\}} [\text{MPa}], (c)_{\{m, sd\}} [\text{MPa}], \phi [\text{degrees}]$	{1.0,0}, {20.0,0}, 0
Linear material group:	
$E_n^* [\text{GPa}], \kappa_n^*, \mu_n$	1.5, 1.5, 0.4

* Flat-jointed material parameters are defined in Table 5 of the base memo.

⁸ Typical properties of Castlegate sandstone are listed in footnote 4 of the Example Materials 1 memo.

⁹ A 2D flat-jointed clumped material can be created in the same way as for the 2D contact-bonded material example.

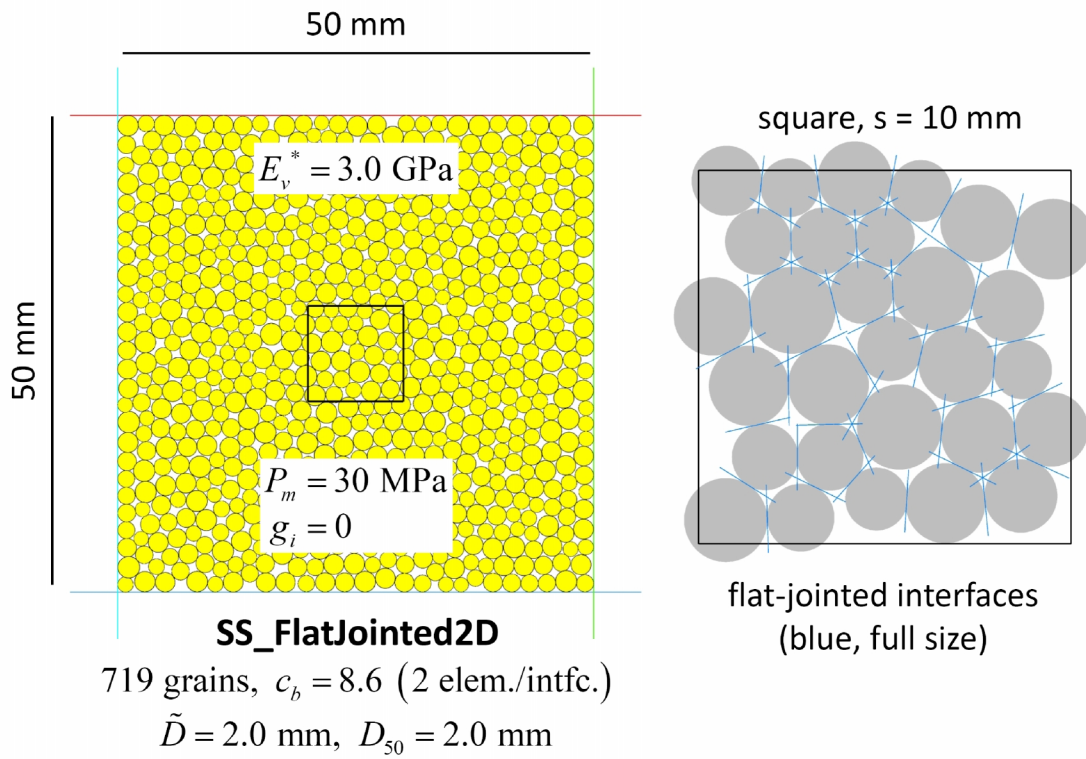


Figure 4 *SS_FlatJointed2D material at the end of material genesis with grains and flat-jointed interfaces in the microstructural box.*

1.5 Smooth-Jointed Interface Example

The smooth-jointed interface example is in the **MatGen-Interface** example-project directory...

{DP: To be developed and described here...}