How using the engineering constants computed by DIGIMAT-MF in a Finite Element Analysis

In this FAQ, we are explaining you

- which kind of engineering constants are computed by DIGIMAT-MF
- how to use these engineering constants to define an anisotropic material in ABAQUS

Problem description: Example of composite material
Let us consider an isotropic elastic matrix reinforced with long steel fibers which are aligned with respect to the direction 1 of the Representative Volume Element. Although the composite consists of two elastic and isotropic phases, its global response will be anisotropic. We will use DIGIMAT-MF to compute the global stiffness matrix and to extract the engineering constants of the composite material.

Composite material definition

- Matrix (linear and isotropic)
  - Young modulus = 10 MPa
  - Poisson ratio = 0.495

- Inclusions (linear and isotropic)
  - Young modulus = 210000. MPa
  - Poisson ratio = 0.3 MPa
  - Volume fraction = 20%
  - Aspect ratio = 1.e+06 (Long fibers)

    There are two different way to define the same inclusions orientation:

    To obtain transversely isotropic engineering constants:
  - Orientation = fixed (Fibers aligned along the direction 1)
    - Theta angle = 90°
    - Phi angle = 0°

    To obtain orthotropic engineering constants:
  - Orientation = tensor (Fibers aligned along the direction 1)
    - a_{11} = 1.0
    - a_{22} = 0.0
    - a_{33} = 0.0
    - $a_{12} = a_{13} = a_{23}$ = 0.0

- Homogenization model = Mori-Tanaka

- Loading = Uniaxial Tension (Let us note that the global stiffness of the composite doesn't depend on the applied loading)

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After running DIGIMAT-MF for both definition of the inclusion orientation (fixed and described with an orientation tensor), the following set of engineering constants are available:

Engineering constants

- *Transversely isotropic engineering constants :*

  Axial Young's modulus = +4.2008e+004 MPa
  In-plane Young's modulus = +1.9763e+001 MPa
  In-plane Poisson's ratio = +9.7621e-001
  Transverse Poisson's ratio (12) = +4.5569e-001
  In-plane shear modulus = +5.0002e+000 MPa
  Transverse shear modulus = +5.0165e+000

  These engineering constants are computed by default in DIGIMAT-MF if inclusions orientation are described using a fixed orientation (See DIGIMAT-MF's manual for more details).

- *Orthotropic engineering constants :*

  Young's modulus $\mathbf{E_1}$ = +4.2008e+004 MPa
  Young's modulus $\mathbf{E_2}$ = +1.9763e+001 MPa
  Young's modulus $\mathbf{E_3}$ = +1.9763e+001 MPa
  Poisson's ratio ν_{12} = +4.5569e-001
  Poisson's ratio ν_{21} = +2.1438e-004
  Poisson's ratio ν_{13} = +4.5569e-001
  Poisson's ratio ν_{31} = +2.1438e-004
  Poisson's ratio ν_{23} = +9.7621e-001
  Poisson's ratio ν_{32} = +9.7621e-001
  Shear modulus $\mathbf{G_{12}}$ = +5.0165e+000 MPa
  Shear modulus $\mathbf{G_{13}}$ = +5.0165e+000 MPa
  Shear modulus $\mathbf{G_{23}}$ = +5.0002e+000 MPa

  The following material stabilities are satisfied:
  - E1, E2, E3, G12, G13, G23 > 0
  - $|\nu_{12}| < (E_1/E_2)^{1/2}$: $|\nu_{12}|$ = 4.5569e-001 < $(E_1/E_2)^{1/2}$ = 4.6104e+001
  - $|\nu_{13}| < (E_1/E_3)^{1/2}$: $|\nu_{13}|$ = 4.5569e-001 < $(E_1/E_3)^{1/2}$ = 4.6104e+001
  - $|\nu_{23}| < (E_2/E_3)^{1/2}$: $|\nu_{23}|$ = 9.7621e-001 < $(E_2/E_3)^{1/2}$ = 1.0000e+000
  - $1 - \nu_{12}\,\nu_{21} - \nu_{23}\,\nu_{32} - \nu_{13}\,\nu_{31} - 2\nu_{21}\,\nu_{32}\,\nu_{13}$ = 4.6628e-002 > 0
  - $|\nu_{21}| < (E_2/E_1)^{1/2}$: $|\nu_{21}|$ = 2.1438e-004 < $(E_2/E_1)^{1/2}$ = 2.1690e-002
  - $|\nu_{31}| < (E_3/E_1)^{1/2}$: $|\nu_{31}|$ = 2.1438e-004 < $(E_3/E_1)^{1/2}$ = 2.1690e-002
  - $|\nu_{32}| < (E_3/E_2)^{1/2}$: $|\nu_{32}|$ = 9.7621e-001 < $(E_3/E_2)^{1/2}$ = 1.0000e+000

  These engineering constants are computed by default in DIGIMAT-MF if inclusions orientation are described using an orientation tensor (See DIGIMAT-MF's manual for more details).

- *Fully anisotropic :*

  Both definitions of inclusions orientations lead to the same global stiffness matrix. This component of the stiffness matrix can easily be written in a .stf file using DIGIMAT2CAE module (See DIGIMAT documentation for more details):

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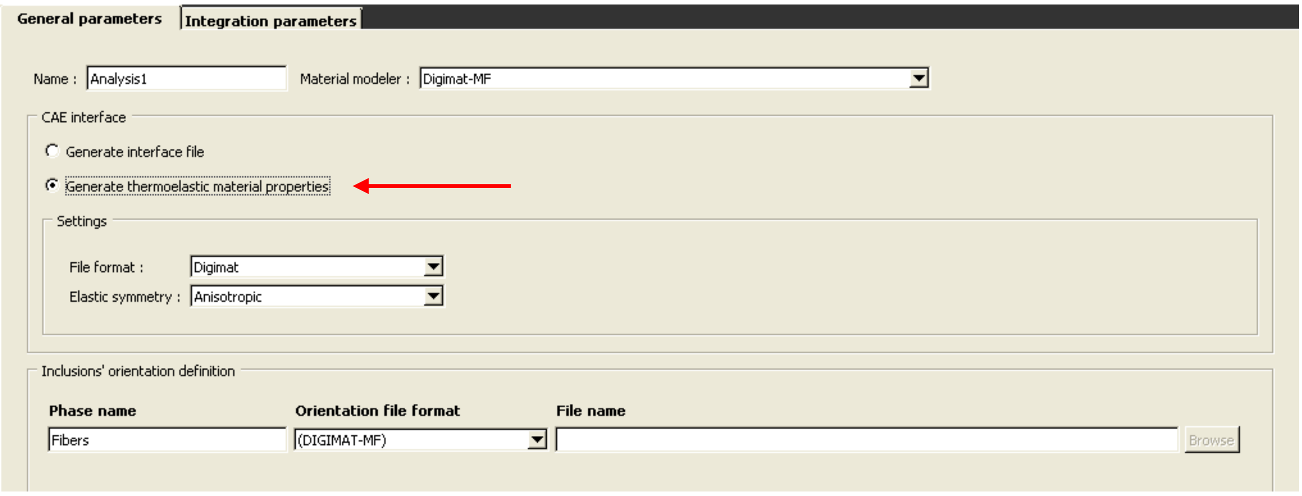

The components of the global stiffness matrix are summarized in the following table:

C_{1111}	C_{1122}	C_{2222}	C_{1133}	C_{2233}
+4.2356e+004	+3.8161e+002	+4.2372e+002	+3.8161e+002	+4.1372e+002
C_{3333}	C_{1112}	C_{2212}	C_{3312}	C_{1212}
+4.2372e+002	+0.0000e+000	+0.0000e+000	+0.0000e+000	+5.0165e+000
C_{1123}	C_{2223}	C_{3323}	C_{1223}	C_{2323}
+0.0000e+000	+0.0000e+000	+0.0000e+000	+0.0000e+000	+5.0002e+000
C_{1113}	C_{2213}	C_{3313}	C_{1213}	C_{2313}
+0.0000e+000	+0.0000e+000	+0.0000e+000	+0.0000e+000	+0.0000e+000
C_{1313}				
+5.0165e+000				

Link with ABAQUS definition

In ABAQUS there is different way to define an anisotropic material using engineering constants predicted by DIGIMAT-MF:

- *Transversely anisotropic*
  Elastic, type= lamina
  E_1, E_2, ν_{12}, G_{12}, G_{13}, G_{23}

  Where the following definition is used:
  - **E1** refers to the axial Young's modulus
  - **E2** refers to the In-plane Young's modulus
  - ν_{12} refers to the Transverse Poisson's ratio
  - **G_{12}** refers to the In-plane shear modulus
  - **G_{13}** refers to the Transverse shear modulus
  - **G_{23}** refers to the Transverse shear modulus

- *Orthotropic*
  Elastic, type = engineering constants
  E_1, E_2, E_3, ν_{12}, ν_{13}, ν_{23}, G_{12}, G_{13}, G_{23}

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- *Fully anisotropic*
  ****Elastic, type = anisotropic***
  C_{1111}, C_{1122}, C_{2222}, C_{1133}, C_{2233}, C_{3333}, C_{1112}, C_{2212}, C_{3312}, C_{1212}, C_{1113}, C_{2213}, C_{3313}, C_{1213}, C_{1313}, C_{1123}, C_{2223}, C_{3323}, C_{1223}, C_{1323}, C_{2323}

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