Example 3d: Triply Periodic GMC Internal RUC Library

This example problem illustrates how to access the internal library of triply periodic repeating unit cell architectures within MAC/GMC 4.0. The loading conditions, materials, and fiber volume fraction remain constant for use with all repeating unit cell architectures. For more information on the code's internal repeating unit cell architectures, see the MAC/GMC 4.0 Keywords Manual Section 3.

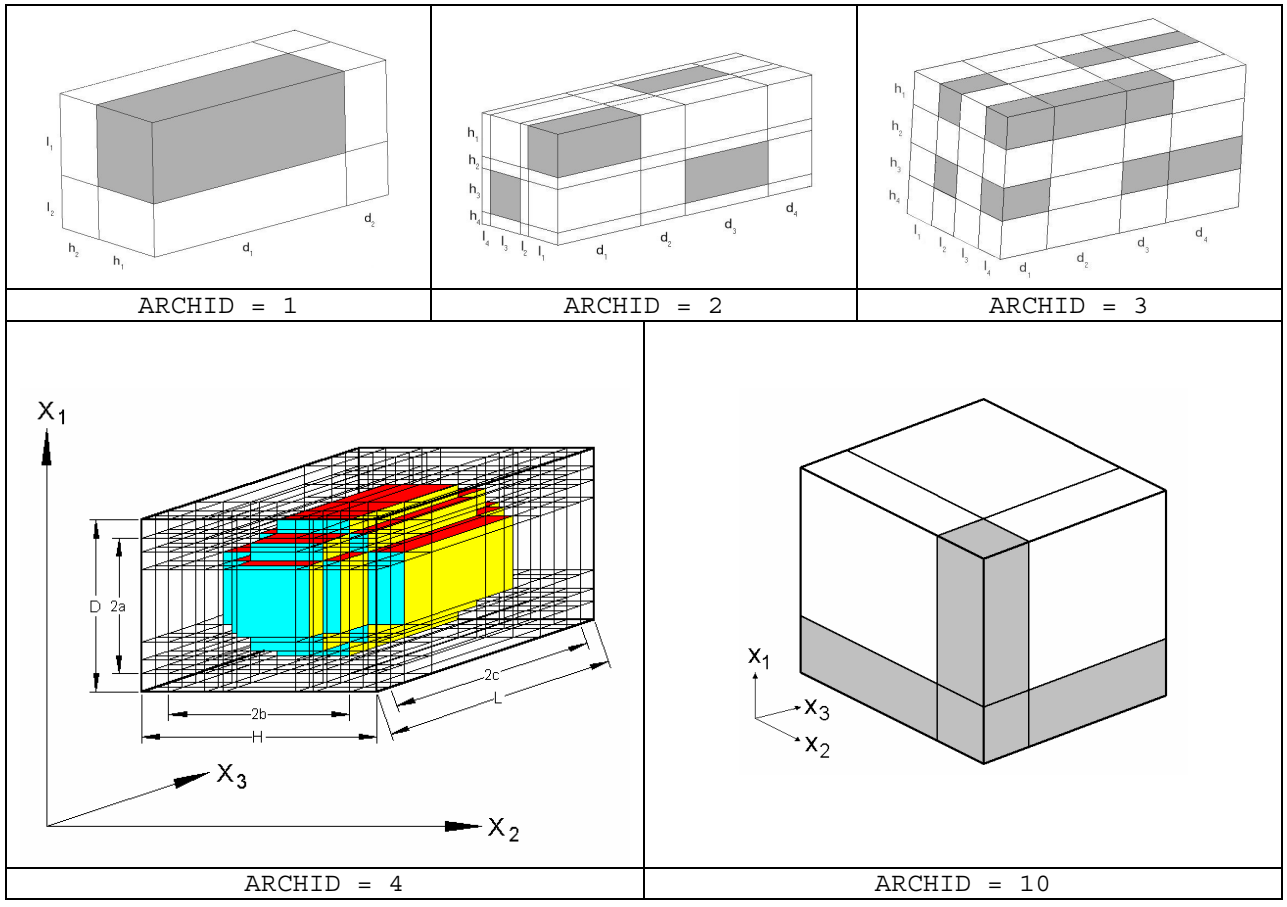

Figure 3.8 MAC/GMC triply periodic repeating unit cell architecture library.

MAC/GMC Input File: `example_3d.mac`

```
MAC/GMC 4.0 Example 3d - Triply Periodic GMC RUC Library
*CONSTITUENTS
  NMATS=2
  M=1 CMOD=6 MATID=E
  M=2 CMOD=4 MATID=A
*RUC
  MOD=3 ARCHID=1 VF=0.25 ASP=2. F=1 M=2
```

```
#  MOD=3 ARCHID=2 VF=0.25 ASP1=2. ASP2=2. F=1 M=2
#  MOD=3 ARCHID=3 VF=0.25 ASP1=2. ASP2=1. DR=1. F=1 M=2
#  MOD=3 ARCHID=4 VF=0.25 &
#        OPT=3 RA=2. RC=1. D=2. H=1. LL=1. F=1 M=2
#  MOD=3 ARCHID=10 VF=0.25 F=1 M=2
*MECH
  LOP=1
  NPT=2 TI=0.,200. MAG=0.,0.02 MODE=1
*THERM
  NPT=2 TI=0.,200. TEMP=650.,650.
*SOLVER
  METHOD=1 NPT=2 TI=0.,200. STP=1.
*PRINT
  NPL=6
*XYPLOT
  FREQ=5
  MACRO=1
   NAME=example_3d X=1 Y=7
  MICRO=0
*END
```

Annotated Input Data

1) Flags: None

2) Constituent materials (***CONSTITUENTS**) [KM_2]:

Number of materials:	2	(NMATS=2)
Materials:	SiC fiber	(MATID=E)
	Ti-21S	(MATID=A)
Constitutive models:	SiC fiber: linearly elastic	(CMOD=6)
	Ti-21S matrix: Isotropic GVIPS	(CMOD=4)

3) Analysis type (***RUC**) → Repeating Unit Cell Analysis [KM_3]:

Analysis model:	Triply periodic GMC	(MOD=3)
RUC architecture:	2×2×2, short fiber, square array	(ARCHID=1)
	Non-overlapping fibers, square diagonal array	(ARCHID=2)
	Off-set short fibers, square array	(ARCHID=3)
	Ellipsoidal fiber approximation, rect. array	(ARCHID=4)
	Open cell	(ARCHID=10)
Fiber volume fractions:	0.25	(VF=0.25)
Fiber aspect ratio	2.	(ASP=2. or ASP1=2.)
Unit cell aspect ratio:	2. or 1.	(ASP=1. or ASP=2.0)
D ratio (ARCHID=3 only):	1.	(DR=0.25)
Ellipsoid inclusion:		
RUC dimensions:	2., 1., 1.	(D=2. H=1. LL=1.)
Semi-major axis ratios:	a/b = 2., c/b = 1.	(RA=2. RC=1.)
Material assignment:	SiC fiber	(F=1)
	Ti-21S matrix	(M=2)

All five triply periodic repeating unit cell architectures contained in the MAC/GMC 4.0 library are exercised in this example problem. Again, each architecture can be used by commenting and uncommenting the appropriate lines of the input file. `ARCHID=1` through `ARCHID=3` represent different packing arrangements for short fiber composites wherein the fiber cross-section is square. `ARCHID=4` represents an ellipsoidal inclusion, which may be thought of as a three-dimensional generalization of the doubly periodic `ARCHID=6`. Finally, `ARCHID=10` represents a three-dimensional open cell architecture. Diagrams of these architectures are given in Figure 3.8.

For more information on these fiber architectures, see the MAC/GMC 4.0 Keywords Manual Section 3.

4) Loading:

a) Mechanical (**`*MECH`**) [KM_4]:

Loading option:	1	(`LOP=1`)
Number of points:	2	(`NPT=2`)
Time points:	0., 200. sec.	(`TI=0.,200.`)
Load magnitude:	0., 0.02	(`MAG=0.,0.02`)
Loading mode:	strain control	(`MODE=1`)

b) Thermal (**`*THERM`**) [KM_4]:

Number of points:	2	(`NPT=2`)
Time points:	0., 200. sec.	(`TI=0.,200.`)
Temperature points:	650., 650. °C	(`TEMP=650.,650.`)

c) Time integration (**`*SOLVER`**) [KM_4]:

Time integration method:	Forward Euler	(`METHOD=1`)
Number of points:	2	(`NPT=2`)
Time points:	0., 200. sec.	(`TI=0.,200.`)
Time step sizes:	1. sec.	(`STP=1.`)

5) Damage and Failure: None

6) Output:

a) Output file print level (**`*PRINT`**) [KM_6]:

Print level:	6	(`NPL=6`)

b) x-y plots (**`*XYPLOT`**) [KM_6]:

Frequency:	5	(`FREQ=5`)
Number of macro plots:	1	(`MACRO=1`)
Macro plot names:	example_3d	(`NAME=example_3d`)
Macro plot x-y quantities:	ε_{11}, σ_{11}	(`X=1 Y=7`)
Number of micro plots:	0	(`MICRO=0`)

7) End of file keyword: (**`*END`**)

Results

Figure 3.9 shows the simulated response of the triply periodic RUC architectures for this 0.25 fiber volume fraction metal matrix composite. It should be noted that, as the fiber volume fraction of triply periodic composites rises, the GMC predictions can become less accurate. This has been shown by Pahr and Arnold (2002). As the fiber volume fraction rises, the RUC architecture may have thin matrix subcells adjacent to or in between larger fiber subcells. This can cause the theory to over-predict the stress in these thin matrix subcells, which leads to an over-prediction of the inelastic deformation in these subcells and an overall response that is too compliant.

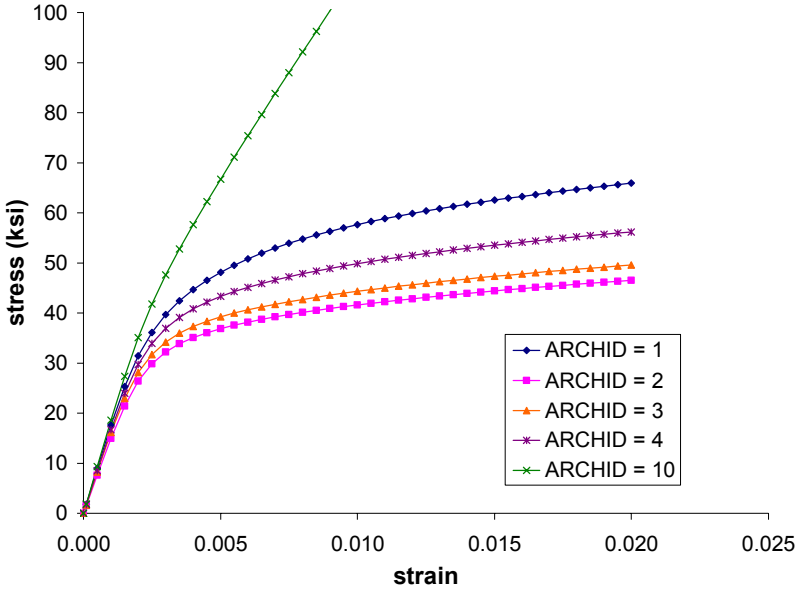

Figure 3.9 Example 3d: plot of the longitudinal tensile stress-strain (σ_{11}-ε_{11}) response for a 0.25 fiber volume fraction triply periodic SiC/Ti-21S composite at 650 °C as represented by the triply periodic repeating unit cell architectures from the MAC/GMC 4.0 architecture library. See Figure 3.8 for the RUC architectures.