Example 3a: Doubly Periodic GMC Internal RUC Library

This example problem illustrates how to utilize the internal library of doubly periodic repeating unit cell architectures within MAC/GMC 4.0. The thermal and mechanical loading conditions, materials, and fiber volume fraction remain constant for use with all repeating unit cell architectures with the exception of ARCHID=9, which represents a composite with two different sized fibers, each with its own volume fraction. Some of the architectures addressed in this example may also be utilized with an interface present between the fiber and the matrix. This interface is composed of a third material that must be specified in ***CONSTITUENTS**. Example 3b analyzes doubly periodic unit cell architectures that do include this distinct interfacial phase. For more information on the code's repeating unit cell architectures, see the MAC/GMC 4.0 Keywords Manual Section 3.

MAC/GMC Input File: **example_3a.mac**

```
MAC/GMC 4.0 Example 3a - Doubly Periodic GMC RUC Library
*CONSTITUENTS
  NMATS=3
  M=1 CMOD=6 MATID=E
  M=2 CMOD=4 MATID=A
  M=3 CMOD=6 MATID=D
*RUC
  MOD=2 ARCHID=1 VF=0.25 F=1 M=2
#  MOD=2 ARCHID=2 VF=0.25 F=1 M=2
#  MOD=2 ARCHID=3 VF=0.25 F=1 M=2
#  MOD=2 ARCHID=4 XA=0.2 VF=0.25 F=1 M=2
#  MOD=2 ARCHID=6 R=1.0 VF=0.25 F=1 M=2
#  MOD=2 ARCHID=7 R=1.0 VF=0.25 F=1 M=2
#  MOD=2 ARCHID=9 VF1=0.1 RAD1=50. VF2=0.15 RAD2=71. R=1. F=3,1 M=2
#  MOD=2 ARCHID=11 R=2.0 VF=0.25 F=1 M=2
#  MOD=2 ARCHID=13 R=1.0 VF=0.25 F=1 M=2
*MECH
  LOP=2
  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_3a X=2 Y=8
  MICRO=0
*END
```

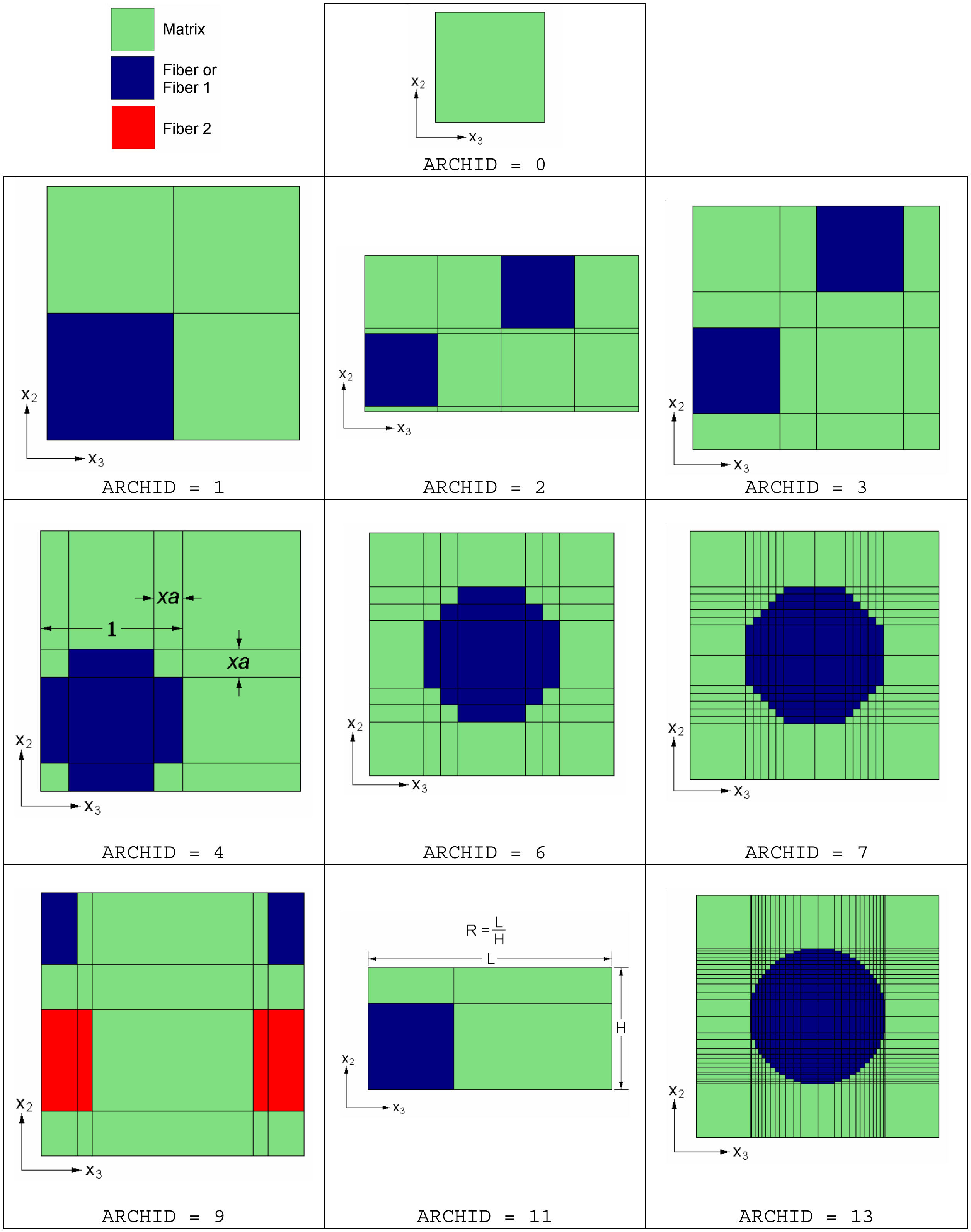

Figure 3.1 MAC/GMC 4.0 doubly periodic repeating unit cell (RUC) architecture library.

Annotated Input Data

1) Flags: None

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

Number of materials:	3	(NMATS=3)
Materials:	SiC fiber	(MATID=E)
	Ti-21S	(MATID=A)
	Boron fiber	(MATID=D)
Constitutive models:	SiC fiber: linearly elastic	(CMOD=6)
	Ti-21S matrix: isotropic GVIPS	(CMOD=4)
	Boron fiber: linearly elastic	(CMOD=6)

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

Analysis model:	Doubly periodic GMC	(MOD=2)
RUC architecture:	square fiber, square pack	(ARCHID=1)
	Square fiber, hexagonal pack	(ARCHID=2)
	Square fiber, square diagonal pack	(ARCHID=3)
	Cross shaped fiber, square pack	(ARCHID=4)
	7×7 circular fiber approx., rectangular pack	(ARCHID=6)
	14×14 circular fiber approx., rectangular pack	(ARCHID=7)
	2 different size square fibers, rectangular pack	(ARCHID=9)
	Square fiber, rectangular pack	(ARCHID=11)
	26×26 circular fiber approx., rectangular pack	(ARCHID=13)
Fiber volume fractions:	0.25	(VF=0.25)
	ARCHID=9: Boron = 0.15 SiC = 0.10	(VF1=0.15 VF2=0.1)
Unit cell aspect ratio:	1.0 (square pack), 2.0 for ARCHID=11	(R=1.0 or R=2.0)
Fiber Radii:	50 μm, 71μm (ARCHID=9 only)	(RAD1=50 RAD2=71)
Cross arm length:	0.2 (ARCHID=4 only)	(XA=0.2)
Material assignment:	SiC fiber	(F=1 or F1=1)
	Ti-21S matrix	(M=2)
	Boron fiber (ARCHID=9 only)	(F=3)

All 9 doubly periodic fiber architectures contained in the MAC/GMC 4.0 library are exercised in this example problem. Each architecture can be used by commenting and uncommenting the appropriate lines of the input file. ARCHID=9 is a special case in that it requires 2 fibers with different radii. Note that, while the fiber radii are specified, only the size of the two fibers relative to each other is important, not the actual radii themselves. In addition, because ARCHID=9 requires the packing of the two fibers to be square or rectangular, not all geometries are possible. As such, the fiber volume fraction of the second fiber, the SiC fiber in this example, is adjusted from the specified value to allow the packing arrangement to be correct given the value of the first fiber's volume fraction and the unit cell aspect ratio, R. Finally, for the cross shaped fiber, ARCHID=4, the cross arm length, XA, is the ratio of the length of the arm of the cross to the total length of the cross, where the total length of the cross is set to 1.0 (see Figure 3.1). 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_3a	(NAME=example_3a)
Macro plot x-y quantities:	ε_{22}, σ_{22}	(X=2 Y=8)
Number of micro plots:	0	(MICRO=0)

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

Results

Figure 3.2 shows the effect of refining the fiber cross-section representation within the repeating unit cell for the square fiber packing arrangement. ARCHID=1 is the least refined fiber representation wherein the fiber is a square. Then, the fiber representation becomes more circular for ARCHID=4, ARCHID=6, ARCHID=7, and ARCHID=13. For the case of the transverse tensile response of a 0.25 fiber volume fraction SiC/Ti-21S composite at 650 °C, convergence based on the circular fiber refinement occurs quickly – the cross shaped, 7×7, 14×14, and 26×26 representations give nearly identical results.

Figure 3.3 shows that the hexagonal and rectangular packing arrangements also give nearly identical results for this example. The large aspect ratio (R=2.0) employed with ARCHID=11, however, does have a noticeable effect on the composite response. Since the hybrid composite represented by `ARCHID=9` is a completely different material system, direct comparison with the other results in this example problem is not possible.

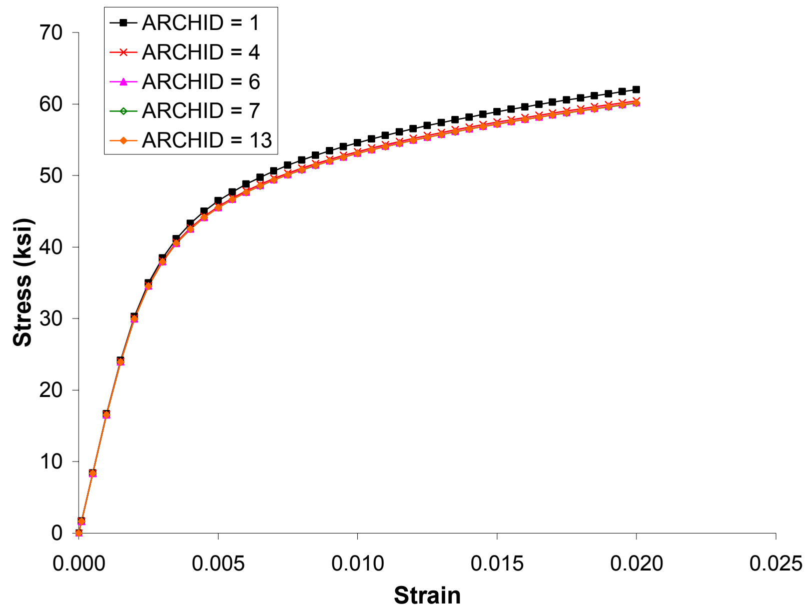

Figure 3.2 Example 3a: plot of the transverse tensile stress-strain (σ_{22}-ε_{22}) response for a 0.25 fiber volume fraction SiC/Ti-21S composite at 650 °C as represented by repeating unit cell architectures 1, 4, 6, 7, and 13 from the MAC/GMC 4.0 architecture library.

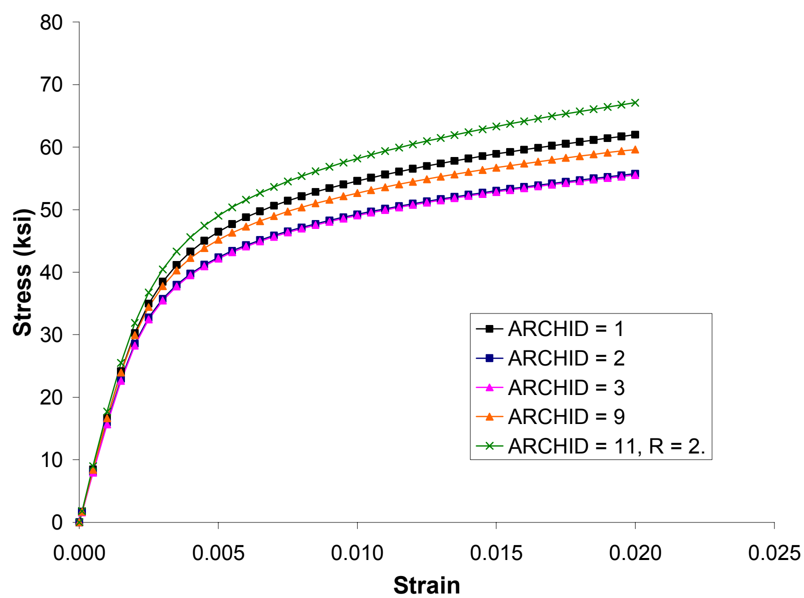

Figure 3.3 Example 3a: plot of the transverse tensile stress-strain (σ_{22}-ε_{22}) response for a 0.25 fiber volume fraction SiC/Ti-21S composite at 650 °C as represented by repeating unit cell architectures 1, 2, 3, and 11 from the MAC/GMC 4.0 architecture library, plus the response of a hybrid 0.15 Boron - 0.07439 SiC / Ti-21S composite.