Example 3b: Doubly Periodic RUC Library with Interface

This example problem illustrates the internal library of doubly periodic repeating unit cell architectures within MAC/GMC 4.0 that include a distinct interfacial phase. While the applied loading employed in this example is identical to Example 3a, an additional material is present here that was not in this previous example. This additional material (with user-input material properties) is used for the interface within the analyzed composites. 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_3b.mac**

```
MAC/GMC 4.0 Example 3b - Doubly Periodic GMC RUCs w/ interface
*CONSTITUENTS
  NMATS=4
  M=1 CMOD=6 MATID=E
  M=2 CMOD=4 MATID=A
  M=3 CMOD=4 MATID=U MATDB=1  &
   EL=11700.,11700.,0.365,0.365,4285.7,1.E-6,1.E-6 &
   VI=0.8E-8,0.1,0.1E-5,0.85E-3,0.05,3.3,1.8,1.35,0.1,0.,0.
  M=4 CMOD=6 MATID=D
*RUC
  MOD=2 ARCHID=1 VF=0.25 RAD=71. RITFR=0.1 F=1 M=2 I=3
#  MOD=2 ARCHID=2 VF=0.25 RAD=71. RITFR=0.1 F=1 M=2 I=3
#  MOD=2 ARCHID=3 VF=0.25 RAD=71. RITFR=0.1 F=1 M=2 I=3
#  MOD=2 ARCHID=6 R=1.0 VF=0.25 RITFR=0.1 F=1 M=2 I=3
#  MOD=2 ARCHID=9 VF1=0.10 RAD1=50. RITFR1=0.1 &
#                 VF2=0.15 RAD2=71. RITFR2=0.1 R=1. F=4,1 M=2 I=3,3
#  MOD=2 ARCHID=11 R=2.0 VF=0.25 RAD=71. RITFR=0.1 F=1 M=2 I=3
*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=0.01
*PRINT
  NPL=6
*XYPLOT
  FREQ=5
  MACRO=1
   NAME=example_3b X=2 Y=8
  MICRO=0
*END
```

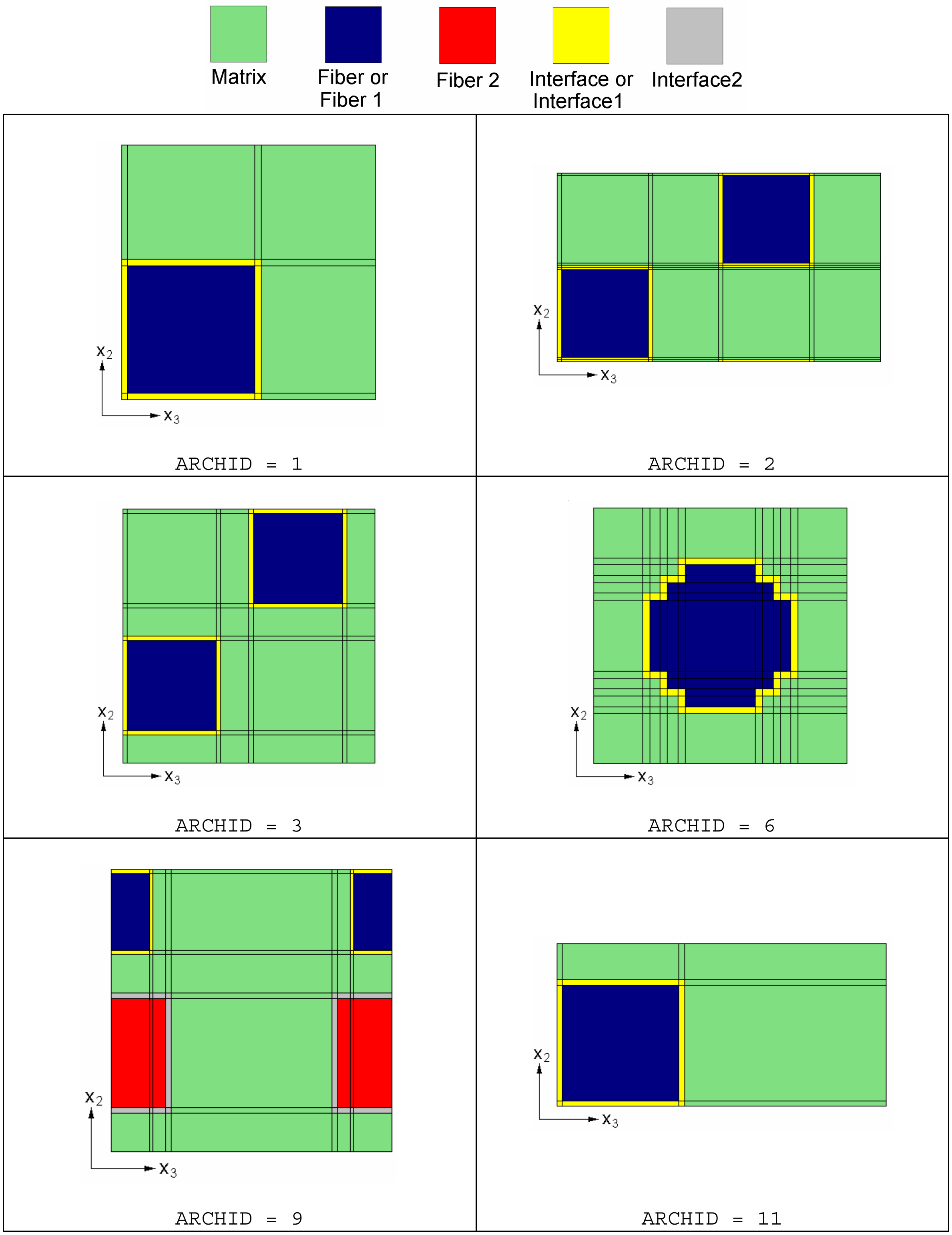

Figure 3.4 MAC/GMC 4.0 doubly periodic repeating unit cell (RUC) architecture with interface library.

Annotated Input Data

1) Flags: None

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

Number of materials:	4	(NMATS=4)
Materials:	SiC fiber	(MATID=E)
	Ti-21S	(MATID=A)
	Fictional interface material	(MATID=U)
	Boron fiber	(MATID=D)
Constitutive models:	SiC fiber: linearly elastic	(CMOD=6)
	Ti-21S matrix: isotropic GVIPS	(CMOD=4)
	Interface: isotropic GVIPS	(CMOD=4)
	Boron fiber: linearly elastic	(CMOD=6)
Source for user props:	Read from input file	(MATDB=1)

A material intended to serve as the interface has been specified using user-defined material properties in conjunction with the isotropic GVIPS constitutive model. This material has been given elastic properties identical to Ti-21S at 650 °C, but its viscoplastic properties cause the material to flow to a much greater extent than does the Ti-21S matrix. This situation is intended to simulate the behavior of a weak interfacial bond within the composite. An example of an alternative more computationally efficient approach to simulating this weak interfacial behavior is examined in Example Problem 5e.

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)
	7×7 circular fiber approx., rectangular pack	(ARCHID=6)
	2 square fibers of different size, square pack	(ARCHID=9)
	Square fiber, rectangular pack	(ARCHID=11)
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:	SiC fiber: 71µm	(RAD=71 or RAD2=71)
	Boron fiber: 50 µm	(RAD1=50)
Material assignment:	SiC fiber	(F=1)
	Ti-21S matrix	(M=2)
	Interface material	(I=3)
	Boron fiber (ARCHID=9 only)	(F=4)

All six doubly periodic fiber architectures contained in the MAC/GMC 4.0 library that included a distinct interface are exercised in this example problem. Each architecture can be used by commenting and uncommenting the appropriate lines of the input file. As in Example 3a, ARCHID=9 is a special case in that it requires 2 fibers with different radii as well as two interfaces. 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 user 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. 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:	1	(FREQ=1)
Number of macro plots:	1	(MACRO=1)
Macro plot names:	example_3b	(NAME=example_3b)
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 3.5 shows that, when compared to Figure 3.2 and Figure 3.3, that the inclusion of the weak interface within the MAC/GMC repeating unit cell architecture has a major impact on the simulated transverse response of the composite. As stated earlier, an alternative approach to simulating composites with weak fiber-matrix interfaces is presented in Example 5e.

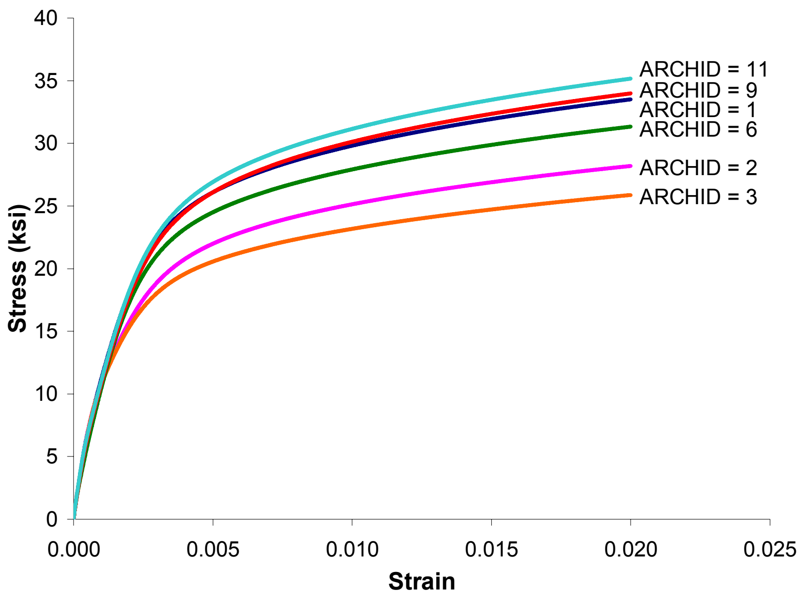

Figure 3.5 Example 3b: plot of the transverse tensile stress-strain (σ_{22}-ε_{22}) response for a 0.25 fiber volume fraction SiC/Ti-21S composite at 650 °C as represented by repeating unit cell architectures MAC/GMC 4.0 architecture library, plus the response of a hybrid 0.15 Boron - 0.07439 SiC / Ti-21S composite, all with interfaces.