# Example 3e: User-Defined Triply Periodic GMC Architecture

This example problem demonstrates how users can input their own triply periodic repeating unit cell architecture. In particular, a periodic [0°/90°] fiber architecture subjected to an applied strain of 0.02 at 650 °C is analyzed. The geometry of the repeating unit cell is shown in Figure 3.10. It should be noted that while the fiber architecture contains 0° and 90° fibers, this problem does not truly simulate a laminate. The represented material is periodic, so it repeats in all three coordinate directions to form a continuum. Therefore, although the RUC has an appearance similar to that of an asymmetric [0°/90°] laminate, no bending will result. A laminate is different in that it has a finite thickness, and the lamination theory formulation is based on a plane stress condition. See the MAC/GMC 4.0 Keywords Manual Section 3 for additional information on the code's repeating unit cell architectures.

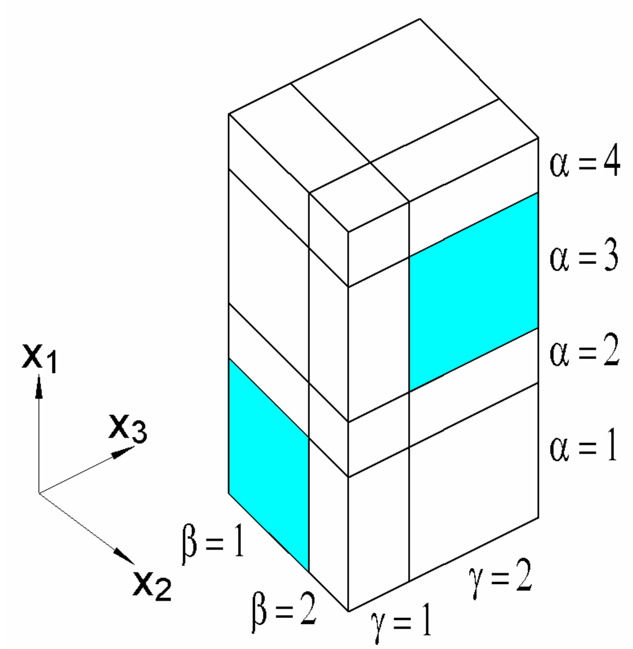


**Figure 3.10** Geometry of the user-defined repeating unit cell architecture employed in Example 3e to simulate the response of a periodic [0°/90°] composite.

## MAC/GMC Input File: `example_3e.mac`

```
MAC/GMC 4.0 Example 3c - [0/90] architecture using 3-d gmc
*CONSTITUENTS
  NMATS=2
  M=1 CMOD=6 MATID=E
  M=2 CMOD=4 MATID=A
*RUC
  MOD=3 ARCHID=99
  NA=4 NB=2 NG=2
  D=0.67823,0.32177,0.67823,0.32177
```

```
  H=0.67823,0.32177
  L=0.32177,0.67823
# -- gamma = 1
  SM=2,2
  SM=2,2
  SM=2,2
  SM=1,2
# -- gamma = 2
  SM=2,2
  SM=1,1
  SM=2,2
  SM=1,2
*MECH
  LOP=1
#  LOP=2
#  LOP=3
  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=3
   NAME=example_3e_11 X=1 Y=7
   NAME=example_3e_22 X=2 Y=8
   NAME=example_3e_33 X=3 Y=9
  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) |
| Architecture: | User-defined | (ARCHID=99) |
| No. subcells in x1-dir.: | 4 | (NA=4) |
| No. subcells in x2-dir.: | 2 | (NB=2) |
| No. subcells in x3-dir.: | 2 | (NG=2) |
| Subcell depths: | see input file | (D=0.67823,…) |
| Subcell heights: | see input file | (H=0.67823,…) |

| | | |
|---|---|---|
| Subcell lengths: | see input file | (`L=0.32177,…`) |
| Material assignment: | see input file | (`SM=…`) |

The materials that occupy each subcell are specified with `SM=…`. The order in which the materials are specified is: 1) ascending groups for each value of γ, 2) descending lines for each value of α, and 3) ascending comma separated material numbers for each value of β. That is, in the present example, we have,

```
# -- gamma = 1
  SM=M(4,1,1),M(4,2,1)
  SM=M(3,1,1),M(3,2,1)
  SM=M(2,1,1),M(2,2,1)
  SM=M(1,1,1),M(1,2,1)
# -- gamma = 2
  SM=M(4,1,2),M(4,2,2)
  SM=M(3,1,2),M(3,2,2)
  SM=M(2,1,2),M(2,2,2)
  SM=M(1,1,2),M(1,2,2)
```

where, `M(α,β,γ)` is the material number assigned to subcell (α,β,γ). For more information on the user-defined repeating unit cell architecture, see the MAC/GMC 4.0 Keywords Manual Section 3.

4) Loading:

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

| | | |
|---|---|---|
| Loading option: | 1, 2, or 3 | (`LOP=1`, `LOP=2`, or, `LOP=3`) |
| 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`) |

☞ Note: The desired loading option is selected by commenting and uncommenting the appropriate lines of the input file.

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_3e_11 | (NAME=example_3e_11) |
| | example_3e_22 | (NAME=example_3e_22) |
| | example_3e_33 | (NAME=example_3e_33) |
| Macro plot x-y quantities: | $\varepsilon_{11}$, $\sigma_{11}$ | (X=1 Y=7) |
| | $\varepsilon_{22}$, $\sigma_{22}$ | (X=2 Y=8) |
| | $\varepsilon_{33}$, $\sigma_{33}$ | (X=3 Y=9) |
| Number of micro plots: | 0 | (MICRO=0) |

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

## Results

Figure 3.11 shows that the tensile response of the periodic [0°/90°] composite in the two in-plane coordinate directions ($x_2$ and $x_3$) is identical, as expected. In the out-of-plane direction ($x_1$), the overall tensile response is more compliant due to the absence of continuous reinforcement in this direction.

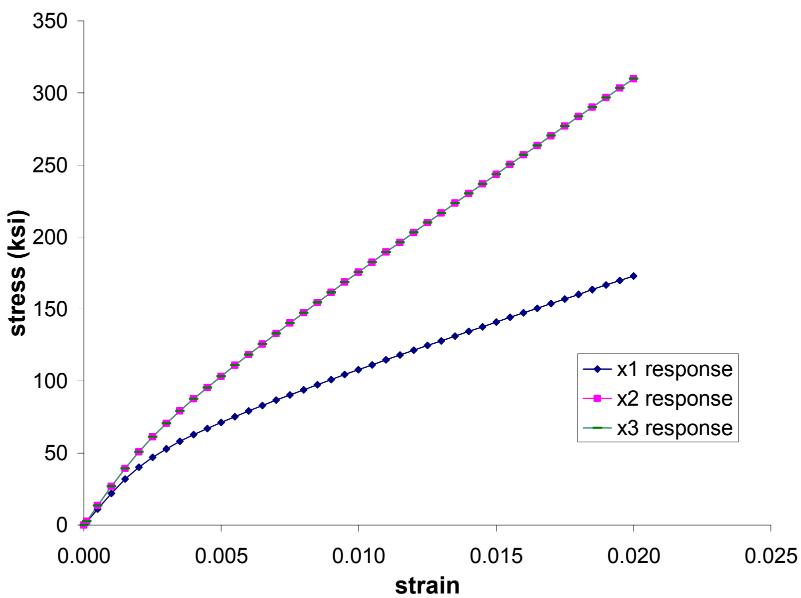


**Figure 3.11** Example 3e: plot of the normal tensile stress-strain response in each of the three coordinate directions for a 0.46 fiber volume fraction periodic [0°/90°] SiC/Ti-21S composite at 650 °C as represented by the user-defined triply periodic repeating unit cell architecture shown in Figure 3.10.