4.2.13 RVE Data:

Purpose: Select RVE representing desired fiber packing arrangement/architecture.

❋MRVE
IDP=*idp*

For Double Periodic RVE (i.e., MOD=1):

☞ **Note:** The following data is entered on the same line as IDP (except where noted)

Without Interface:

- For IDP = 0
  no further data required **(only used for a monolithic layer in a laminate)**
- For IDP = 1, 2,or 3
  VF=*vf*
- For IDP = 4
  VF=*vf*   XA=*xa*
- For IDP = 6
  VF=*vf*   R=*R*
- For IDP = 7
  VF=*vf*   R=*R*
- For IDP = 9
  VF1=*vf1*   RAD1=*rad1*   VF2=*vf2*   RAD2=*rad2*   R=*R*
- For IDP = 11
  VF=*vf*   RAD=*rad1*   R=*R*
- For IDP = 13
  VF=*vf*   R=*R*

With Interface:

- For IDP = 1, 2,or 3
  VF=*vf*   RAD=*rad1*   CPER=*cper*
- For IDP = 4
  ☞ **Currently NOT Available**
- For IDP = 6
  VF=*vf*   R= *R*   CPER=*cper*
- For IDP = 7
  ☞ **Currently NOT Available**

- For IDP = 9
  VF1=*vf1* RAD1=*rad1* CPER1=*cper1* VF2=*vf2* &
  RAD2=*rad2* CPER2=*cper2* R=*R*
- IDP = 11
  VF=*vf* RAD=*rad1* R=*R* CPER=*cper*
- For IDP = 13
  ☞ **Currently NOT Available**

%

where:

vf, vf1, vf2 =	the fiber volume ratios
rad, rad1, rad2 =	fiber radii
cper, cper1, cper2 =	ratios of interface thickness to fiber radius
xa =	length of the cross, see Fig. 10.

R = X/Y which defines the ratio of distances between fiber centers within a "ply" and those between a "ply" (see Fig. 11)

☞ **Note:** For the laminate option the RVE data has the following input format:

❋MRVE
IDP=idp_{l1}, idp_{l2}, ... idp_{nly}
L=1 VF= ... (rve data for layer 1)
L=2 VF= ... (rve data for layer 2)
:
L=*nly* VF= ... (rve data for layer *nly*)

%

Where:

idp:- unique identifying number of each **Double Periodic** RVE as given below

idp	Description
• 1 =	Square Fiber, Square Pack (original 4-cell model)

$$V_f \leq 1/(1+\Delta)^2$$

RVE shown in Fig. 9

idp	Description
• 2 =	Square Fiber, Triangular (hexagonal) Pack $V_f \leq 0.86602 / (1 + \Delta)^2$ RVE shown in Fig. 9
• 3 =	Square Fiber, Square Diagonal Pack; $V_f \leq 0.5 / (1 + \Delta)^2$ RVE shown in Fig. 9

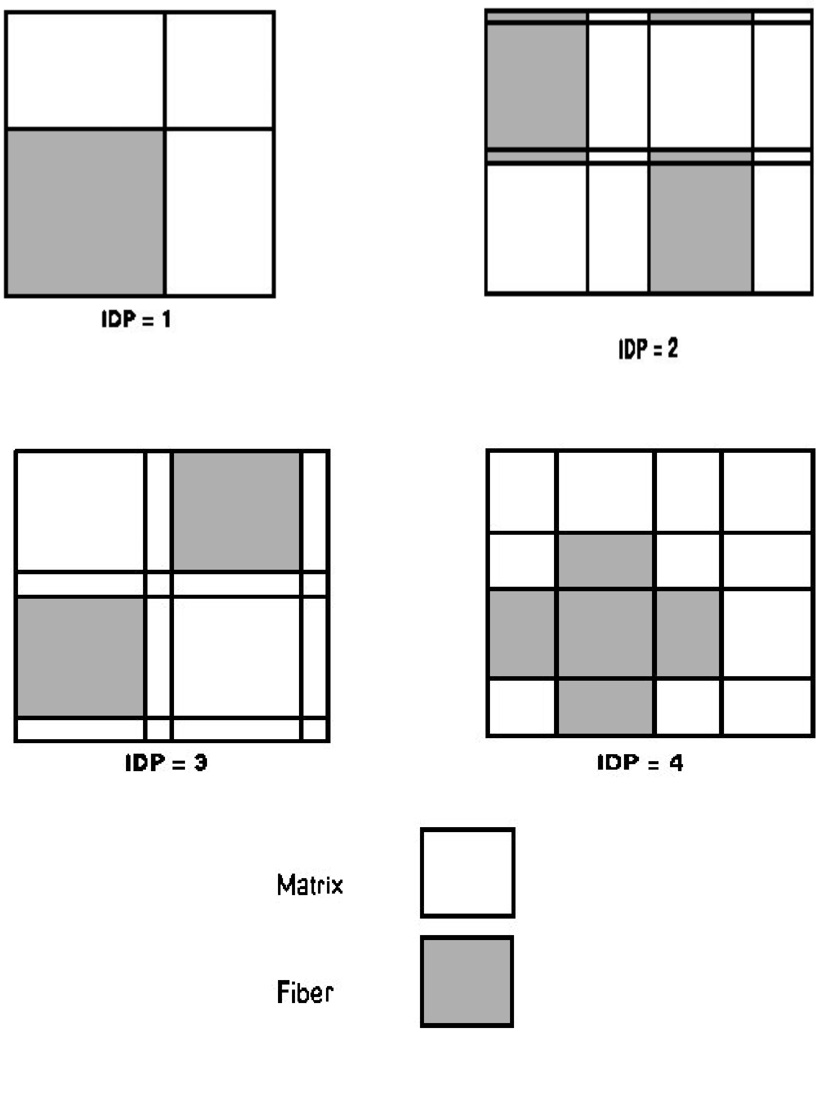


Figure 9: RVE’s Available in **MAC/GMC**

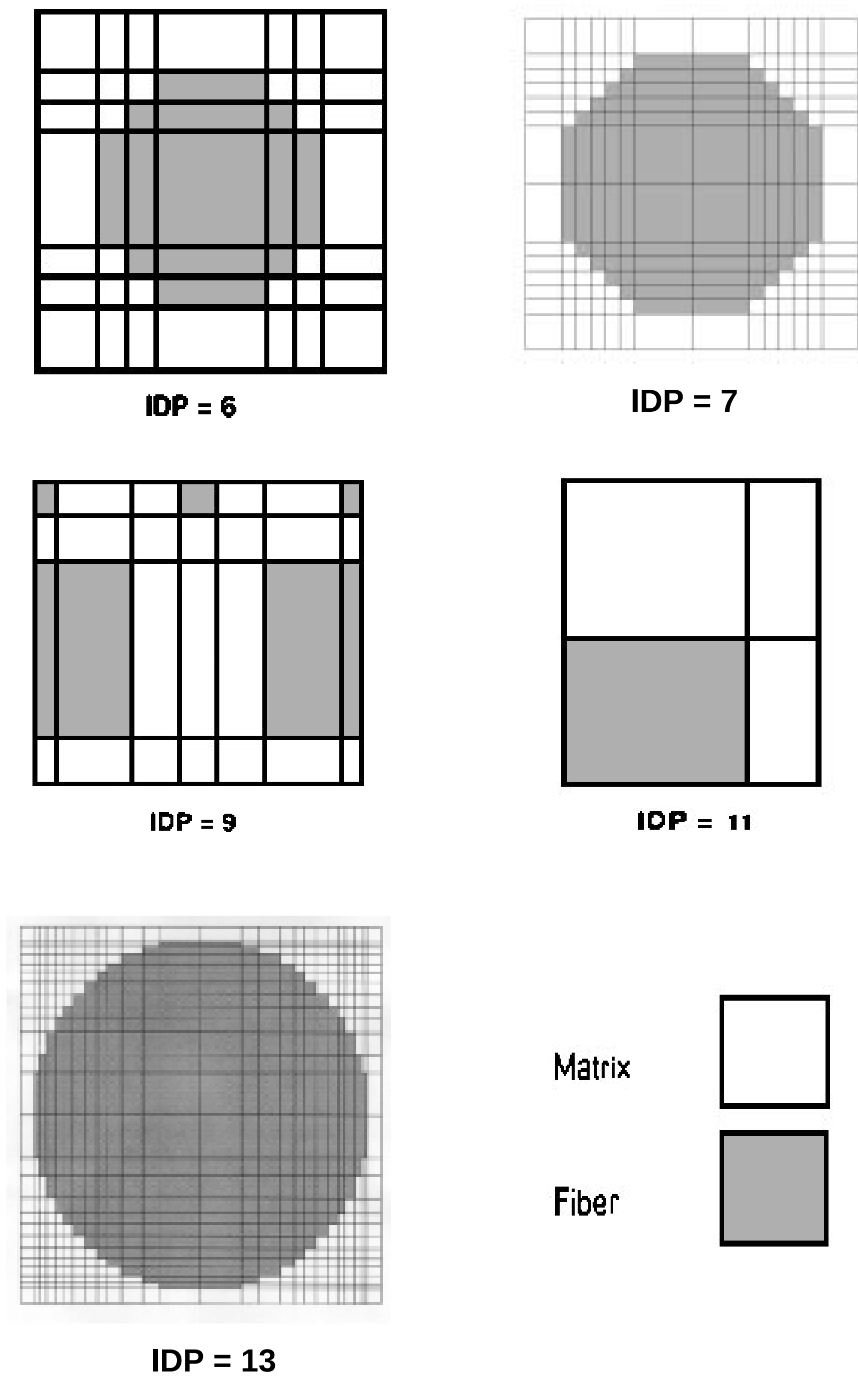


Figure 9 con't: RVE's Available in **MAC/GMC**

idp	Description
• 4 =	Cross Shaped Fiber, Square Pack

$$V_f \le 1 - 4(xa)^2$$

RVE shown in Fig. 9

• 6 = 7x7 Circular Fiber Approximation Rectangular or Square Pack

$$V_f \le \frac{0.8125}{R(1+\Delta)^2} \qquad if \qquad R > 1.0$$

$$V_f \le \frac{R(0.8125)}{(1+\Delta)^2} \qquad if \qquad R < 1.0$$

RVE shown in Fig. 9

• 7= 14x14 Circular Fiber Approximation Rectangular or Square Pack

$$V_f \le \frac{0.8148}{R} \qquad if \qquad R > 1.0$$

$$V_f \le R(0.8148) \qquad if \qquad R < 1.0$$

RVE shown in Fig. 9

• 9 = Two Different Size Square Fibers, Rectangular or Square Pack

$$V_{f_2} \le \frac{1}{R\left[(1+\Delta_2) + (1+\Delta_1)\dfrac{R_{f_1}}{R_{f_2}}\right]^2}$$

$$V_{f_1} \le \frac{2\sqrt{RV_{f_2}}}{\left[\left(\dfrac{R_{f_2}}{R_{f_1}}\right)^2(1+\Delta_2) + \left(\dfrac{R_{f_2}}{R_{f_1}}\right)(1+\Delta_1)\right]}$$

$$\frac{V_{f_1}}{V_{f_2}}\left[\frac{R_{f_1}}{R_{f_2}}\right]^2 \ge 1$$

RVE shown in Fig. 9

☞ **Note:** Two fibers and two interfaces must be defined in *Fiber and *Interface.

☞ **Note:** V_{f_1} will be altered, if necessary, such that an integer number of small fibers fit within the RVE.

idp	Description
• 11 =	Square Fiber, Rectangular Pack

$$V_f \le \frac{1}{R(1+\Delta)^2} \qquad if \qquad R > 1.0$$

$$V_f \le \frac{R}{(1+\Delta)^2} \qquad if \qquad R < 1.0$$

RVE shown in Fig. 9

• 13 = 26 x 26 Circular Fiber, Rectangular or Square Pack

$$V_f \le \frac{0.80613}{R} \qquad if \qquad R > 1.0$$

$$V_f \le 0.80613R \qquad if \qquad R < 1.0$$

RVE shown in Fig. 9

☞ **Note:** R_{f_1} = rad1**,** R_{f_2} = rad2 and if no interface is present**,** Δ **=** *cper*, Δ_1 = *cper1* and Δ_2 = *cper2* should be taken to be zero, in the above formulas.

• 99 = User Defined RVE
Example of RVE representing random packing shown in Fig. 12. Required input shown in **Example I**.

Example: Triangular packing with interface thickness 1% of fiber radius.

❋MRVE
IDP=2 VF=35 RAD=0.07 CPER=0.01 %

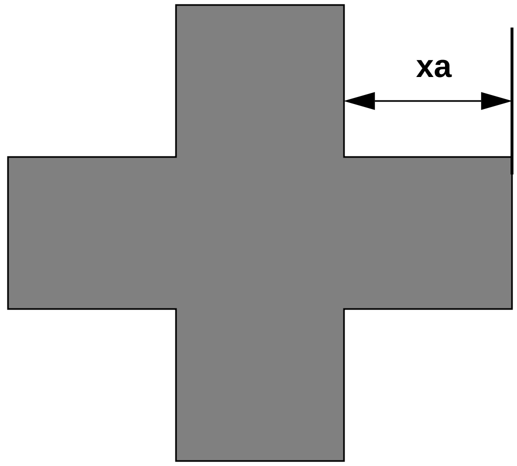


Figure 10: Cross Shaped Fiber Distance xa

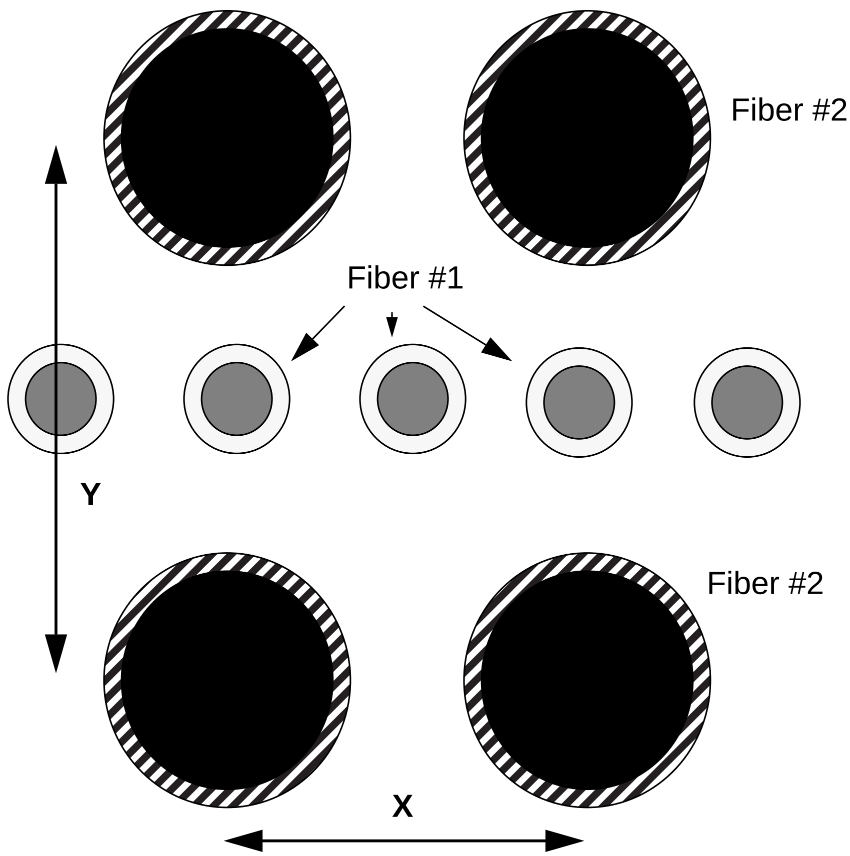


Figure 11: Hybrid Composite RVE; IDP = 9. Large Fiber Spacing Ratio, R=X/Y

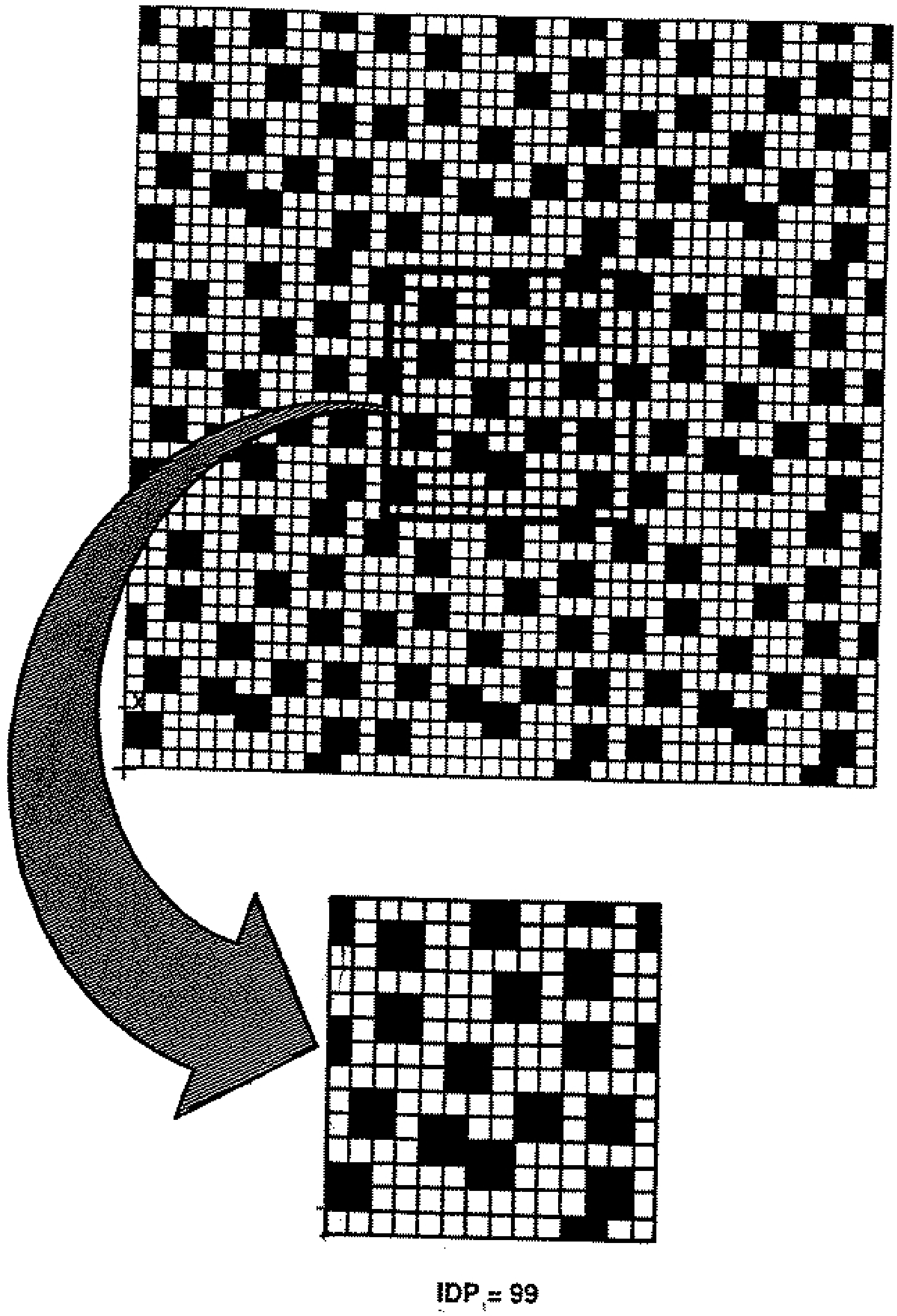


Figure 12: User defined RVE (see **Example I**)

For Triple Periodic RVE (i.e., MOD=2):

☞ **Note:** The following data is entered on the same line as the IDP data, except where noted.

Thus for

- For IDP = 1
  VF=*vf* *ASP=asp*
- For IDP = 2
  VF=*vf* *ASP1=asp1* *ASP2=asp2*
- For IDP = 3
  VF=*vf* *ASP1=asp1* *ASP2=asp2* *DR=dr*

  where,

  a*sp,asp1 - are the aspect ratio of the short fiber (i.e., fiber length/fiber diameter; e.g. in IDP=3 this is* $(d_1 + d_2 + d_3)/ h_1)$

  asp2 - is the aspect ratio of the unit cell , d/h (see Fig. 2)

  dr - is the ratio d_1/d_3 which quantifies the fiber off-set (see Fig. 13)

- For IDP = 4
  One of the following lines should be entered after the IDP data depending upon the option desired
  OPT=1 A=a B=b C=c D=d H=h L=l *%*
  OPT=2 VF=vf A=a B=b C=c RD=rd RL=rl *%*
  OPT=3 VF=vf RA=ra RC=rc D=d H=h L=l *%*
  OPT=4 VF=vf A=a B=b C=c RD=rd RLC= rlc *%*

  where,
  a,b, and c are the ellipsoid's semi-major axes (see Fig. 13)
  d, h and l are the unit cell dimensions (see Fig. 13)
  rd = aspect ratio of d/h
  rl = aspect ratio of l/h
  ra = aspect ratio of a/b
  rc = aspect ratio of c/b
  rlc = aspect ratio of l/(2c)

- For IDP = 10
  VF=*vf*

Where

idp:- unique identifying number of each **Triple Periodic** RVE given Fig. 13

idp	Description
• 1 =	Short fibers in Square array, with equal spacing in all directions (i.e., $d_2 = h_2 = l_2$ see Fig. 13)

$$0 \le V_f \le 1$$

RVE shown in Fig. 13

• 2= Short fibers in Diagonal array, with variable inclusion spacing in the x_1 - direction

$$V_f < \frac{1}{2}\left(\frac{Asp1}{Asp2}\right) \qquad if \qquad Asp1 < Asp2$$

$$V_f < \frac{1}{2}\left(\frac{Asp2}{Asp1}\right)^2 \qquad if \qquad Asp1 > Asp2$$

RVE shown in Fig. 13

• 3= Off-set short fibers in square array, variable fiber spacing in the x_1 - direction --- **NOTE Asp1** > **Asp2**

$$V_f < 4\left(\frac{Asp1}{Asp2}\right)^2 \qquad if \qquad \frac{Asp1}{Asp2} > 2$$

$$V_f < \frac{1}{2}\left(\frac{Asp2}{Asp1}\right) \qquad if \qquad \frac{Asp1}{Asp2} < 2$$

$$V_f > \frac{1}{2}\left(\frac{Asp2}{Asp1}\right)^2$$

RVE shown in Fig. 13

• 4= Ellipsoidal Inclusion

☞ **Note:** Analytical expressions for Vf limits are unavailable as forming this unit cell geometry requires solution of non-linear equations.

☞ **Note:** Use of non-physical ellipsoid unit cell dimensions (e.g., 2b > h) will cause execution of **MAC/GMC** to stop.

• 10= Open cell

$$0 \le V_f \le 1$$

☞ **Note:** Solid material (see Fig. 13) is the matrix material specified in *MATRIX. whereas, the “open” material is the fiber material specified in *FIBER. To simulate a truly “open cell” material, specify a fiber material with the properties of air, thus fiber volume fraction becomes the void fraction

• 99= User defined RVE

☞ **Note: The following is the format for the user defined RVE's, IDP = 99 (see Fig. 12 for an example)**.

1) **For <u>2-D</u> RVE**: (Each line of data must be on a <u>separate</u> line)

NB=*nb*   NG=*ng*
H=h_1, h_2, ... h_{ng}
L=l_1, l_2, ... l_{nb}
CM=$ss_{nb,1}$,$ss_{nb,2}$,...$ss_{nb,ng}$
repeat data for the (*nb* x *ng*) **2-D RVE**
CM=$ss_{1,1}$,$ss_{1,2}$,...$ss_{1,ng}$

2) **For <u>3-D</u> RVE**: (Each line of data must be on a <u>separate</u> line)

NA=*na*   NB=*nb*   NG=*ng*
D=d_1,d_2,...d_{na}
H=h_1, h_2, ... h_{ng}
L=l_1, l_2, ... l_{nb}
CM=$ss_{na,1,1}$,$ss_{na,2,1}$,...$ss_{na,nb,,1}$
CM=$ss_{na-1,1,1}$,$ss_{na-1,2,1}$,...$ss_{na-1,nb,,1}$
repeat data for the (*na* x *nb* x *ng*) **3-D RVE**
CM=$ss_{1,1,ng}$,$ss_{1,2,ng}$,...$ss_{1,nb,ng}$

Where:

$ss_{i,j}$ and $ss_{i,j,k}$ - are the identifying material labels which are given in the following format:

first character: F - for a fiber or M - for matrix
second character: 1, 2, 3, ... for fiber/matrix number 1, 2, 3 ...

na - number of subcells in the alpha direction

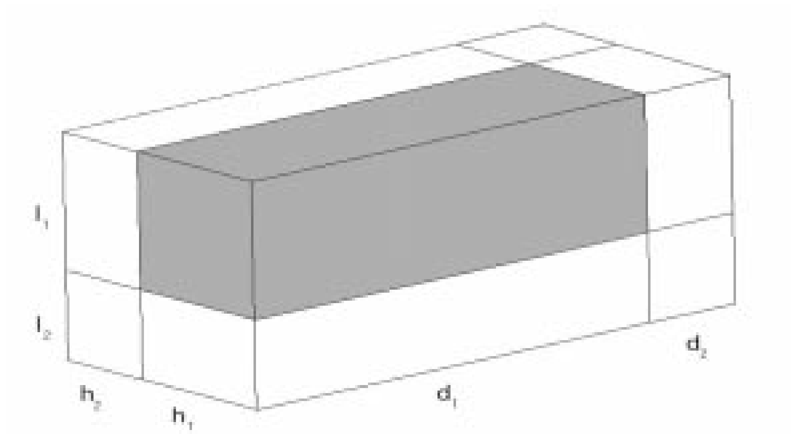
nb - number of subcells in the beta direction

ng - number of subcells in the gamma direction

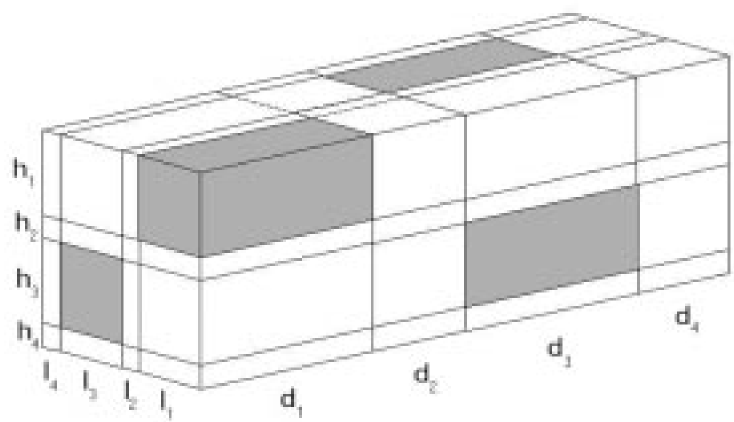
h - the height of each subcell (x_2-dimension)

l - the length of each subcell (x_3- dimension)

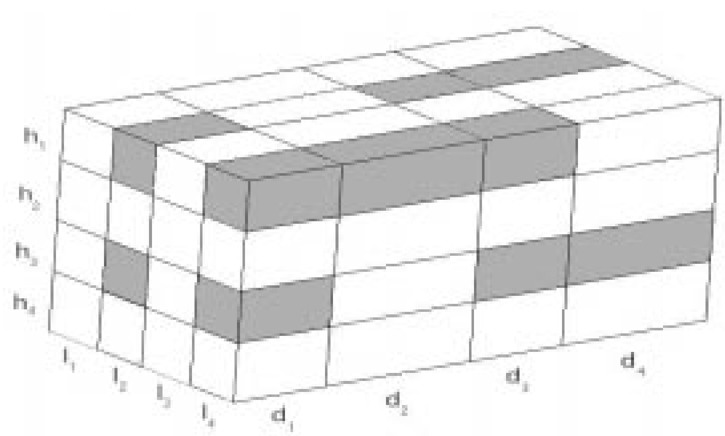
d - the depth of each subcell (x_1- dimension)



IDP = 1

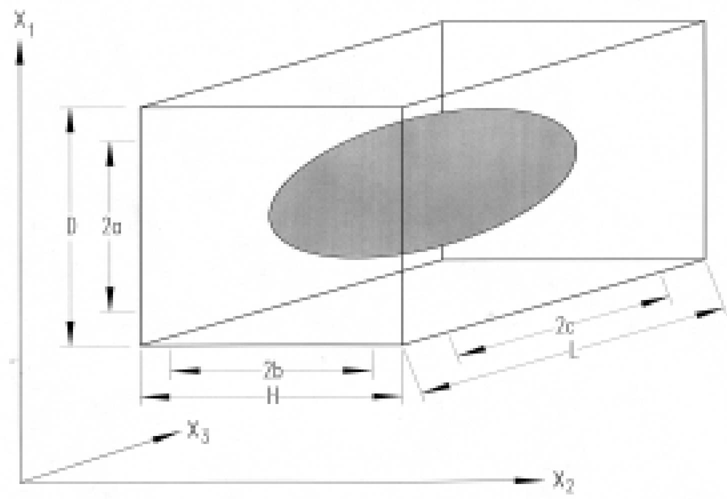


IDP = 2

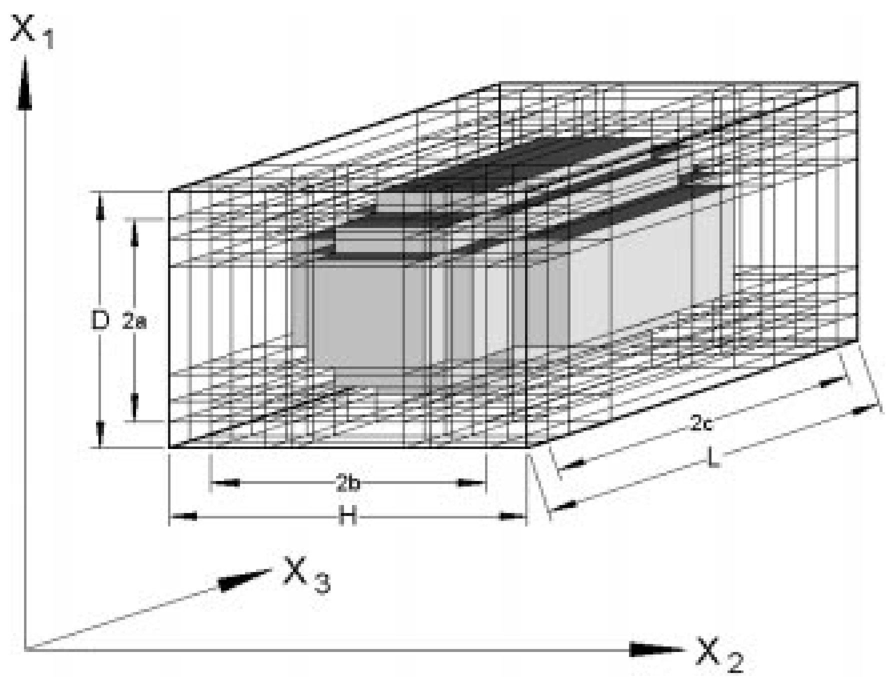


IDP = 3

Figure 13 Available 3-D RVE's

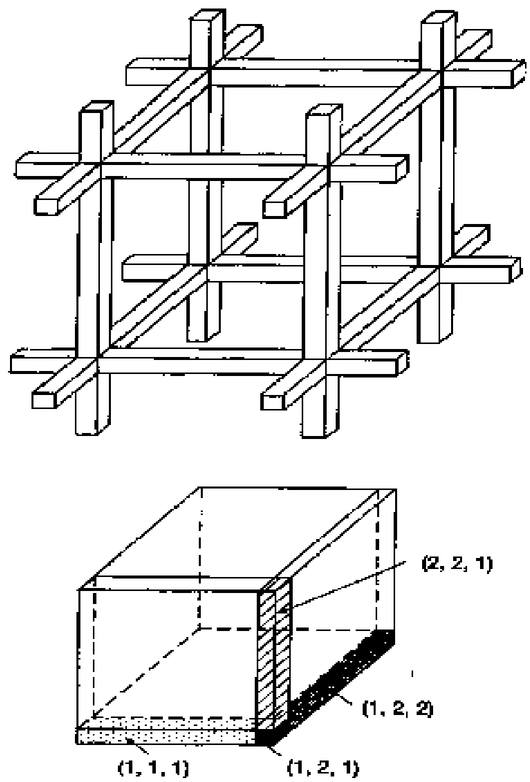


Ellipsoidal Inclusion



Ellipsoidal Inclusion RVE (IDP = 4)

Figure 13 con't: Available 3-D RVE's



IDP=10 - Open cell

Figure 13 con't: Available 3-D RVE's

☞ **Note:** A 2-D (continuous reinforcement) and 3-D (discontinuous reinforcement) example are described next with a detailed example of the user defined inputs being found in **Example I,** 2-D case, and in **Examples H** and **N**, for the 3-D case.

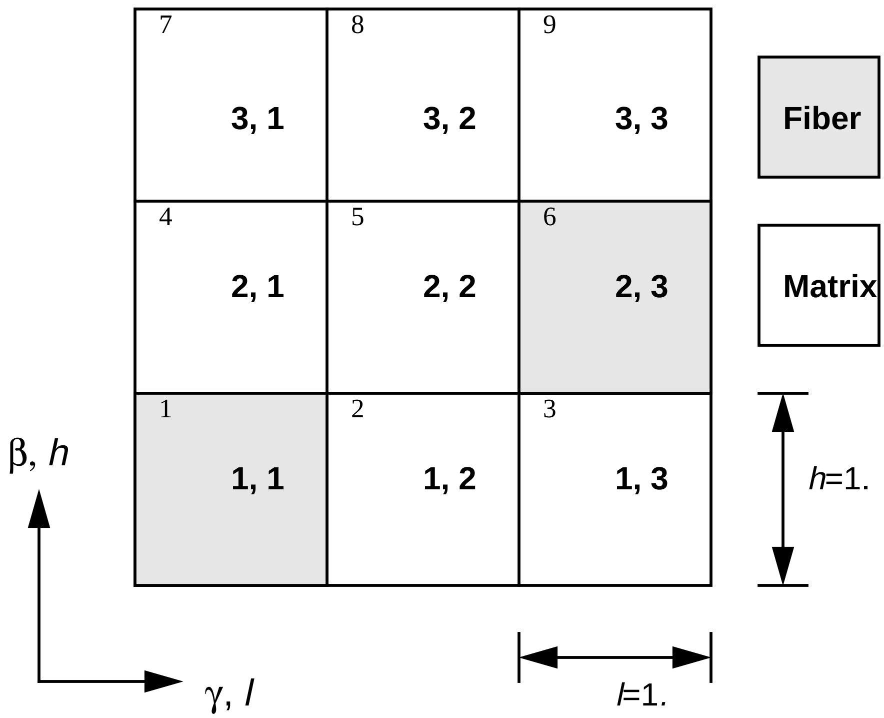


Figure 14

Example: 2-D user defined RVE (as shown above)

❋**MRVE**

IDP=99
NB=3 NG=3
H=1.,1.,1.
L=1.,1.,1.
CM=M1,M1,M1
CM=M1,M1,F1
CM=F1,M1,M1 %

☞ **Note:** the fiber ID is F1 and the matrix ID is M1

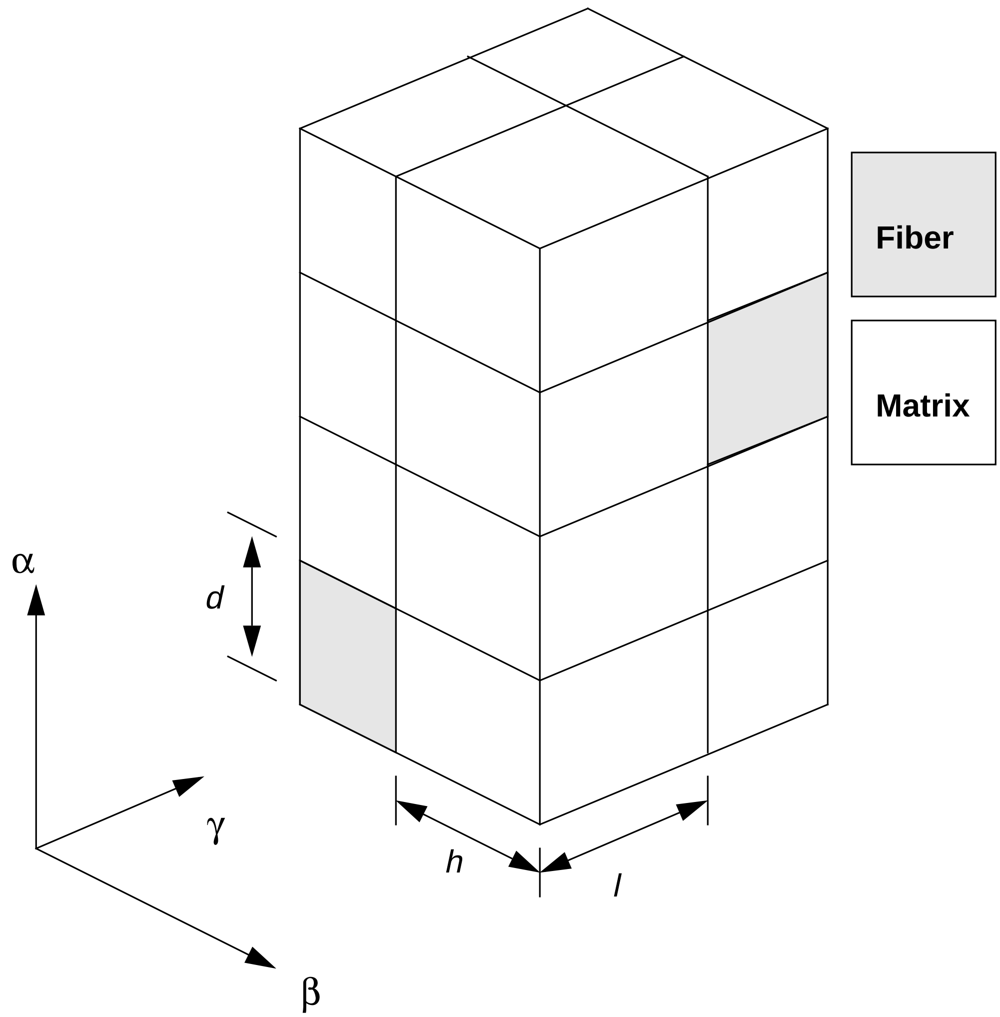


Figure 15

Example: A 3-D User defined RVE (as shown above), representing a [0/90] continuous reinforced laminate composite.

☞ **Note:** The fiber is material number F1 and the matrix is material number M1.

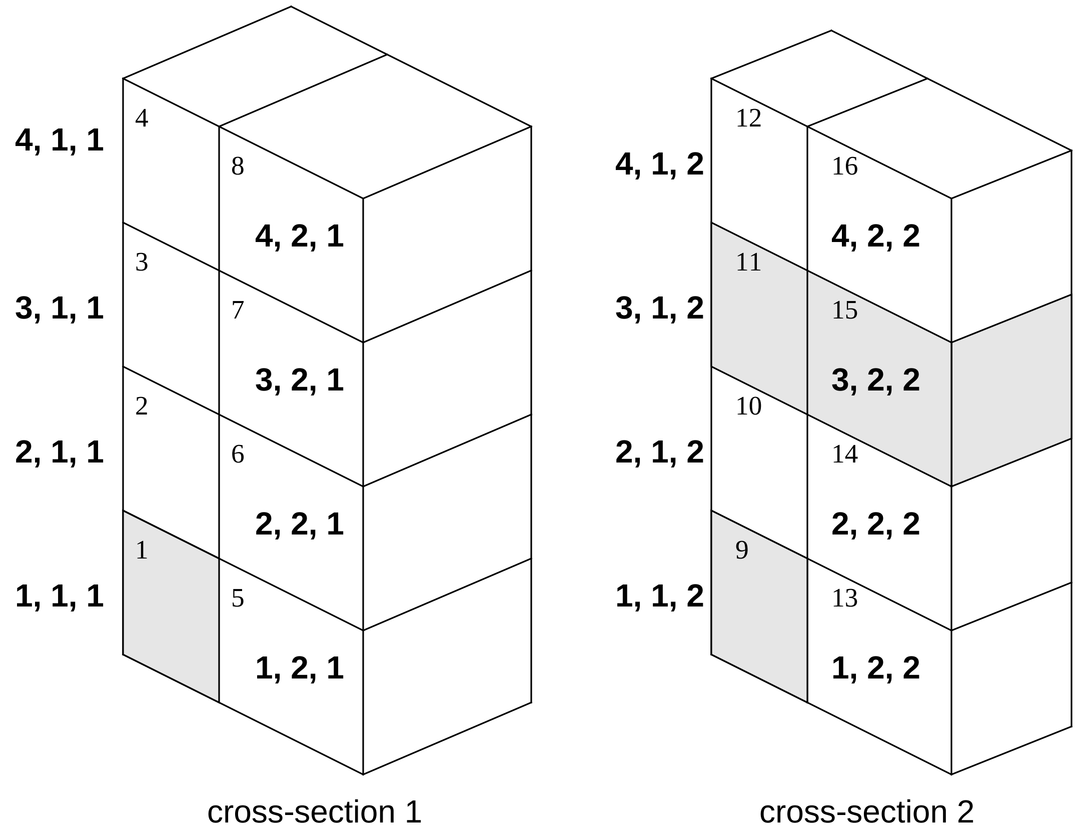


Figure 16

❋MRVE

```
IDP=99    ASP=1.
NA=4   NB=2   NG=2
D=1.,1.,1.,1.
H=1.,1.
L=1.,1.
CM=M1,M1                    rows 1-4 are for cross-section 1 (γ=1)
CM=M1,M1
CM=M1,M1
CM=F1,M1
CM=M1,M1                    rows 5-8 are for cross-section 2 (γ=2)
CM=F1,F1
CM=M1,M1
CM=F1,M1    %
```