Multiscale Analysis of woven plate using SwiftComp-Patran GUI

March, 2019

Xin Liu and Wenbin Yu

Problem Statement

In this example, a 2 by 2 twill woven laminated plate is analyzed using SwiftComp-Patarn GUI. In order to use PCOMP card in Nastran, the effective properties of woven laminar must be obtained from multiscale analysis. At micro-scale, yarn effective properties are obtained from fiber and matrix using SwiftComp solid model, and woven laminar properties are obtained from yarns and matrix using SwiftComp solid model.

The layup of the laminated plate is [45/0/0/45/0/0/45]s, and the ply thickness is 0.2 mm. Assume the plate has dimensions Length * Width = 50mm * 50mm. The plate is subjected to fixed-free boundary conditions, and a uniform pressure is applied at free end with magnitude 10 MPa along x-direction (Fig. 1).

The fiber properties are $E_1 = 276\,\text{GPa}$, $E_2 = E_3 = 19.50\,\text{GPa}$, $G_{12} = G_{13} = 70\,\text{GPa}$, $G_{23} = 5.73\,\text{GPa}$, $\nu_{12} = \nu_{13} = 0.28, \nu_{23} = 0.70$,the matrix properties are $E = 4.76\,\text{GPa}$, $\nu = 0.37$. The fiber volume fraction is 0.6.

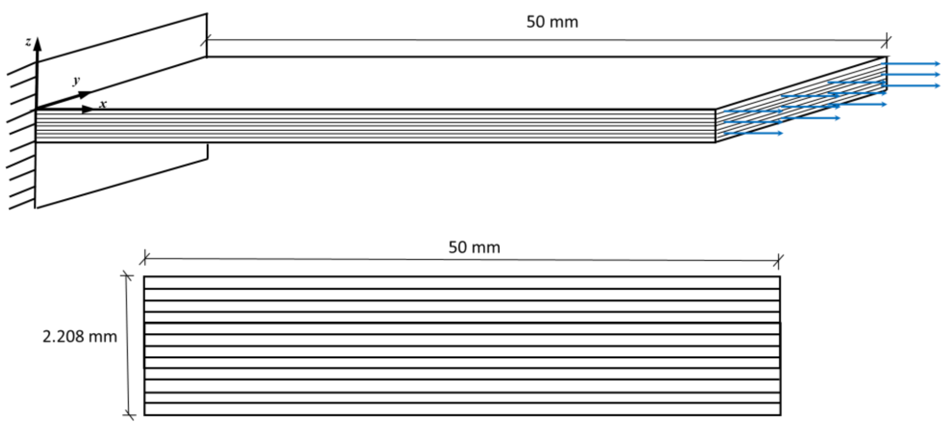

Fig. 1 The clamped structure

Microscale homogenization

In order to obtain the effective properties of yarns, homogenization analysis is needed by considering fibers and matrix. The microstructure of the yarn is usually idealized a square pack and the SG is shown in Figure 2.

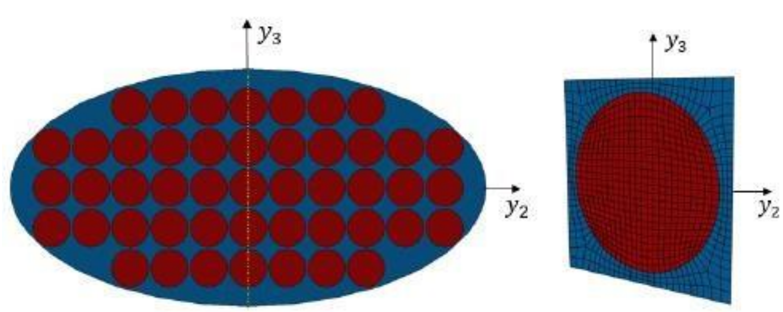

Fig. 2 Yarn cross-section and its SG

Open Patran and start a new database named yarn_SG as shown in Fig.3. Click *Geometry>Surface->XYZ*, then input the parameters shown in Fig. 4 to center the SG at the origin so that the reference surface is located in the mid-plane of the structure, and click apply. Next select *Curves->2D Circle*. Input the radius of fiber circle 0.437 as the volume fraction is 0.6 and click apply as shown in Fig. 5. If we define the length of each edge is *a*, the radius of fiber is *r* and the fiber volume fraction is v_f. The relation of radius and fiber volume fraction is given in Eq. (1)

$$\frac{S_f}{S} = \frac{\pi r^2}{a^2} = v_f \Rightarrow r = \sqrt{\frac{v_f \times a^2}{\pi}} \quad (1)$$

Now the geometry of the SG is still not ready, we need to break the entire domain to be matrix and fiber. Select *Action: Edit*, *Object: Surface and Method: Break* in the Geometry control window and select the corresponding surface and curve as shown in Fig. 6. Click "Yes" to finish the geometry generation of this SG.

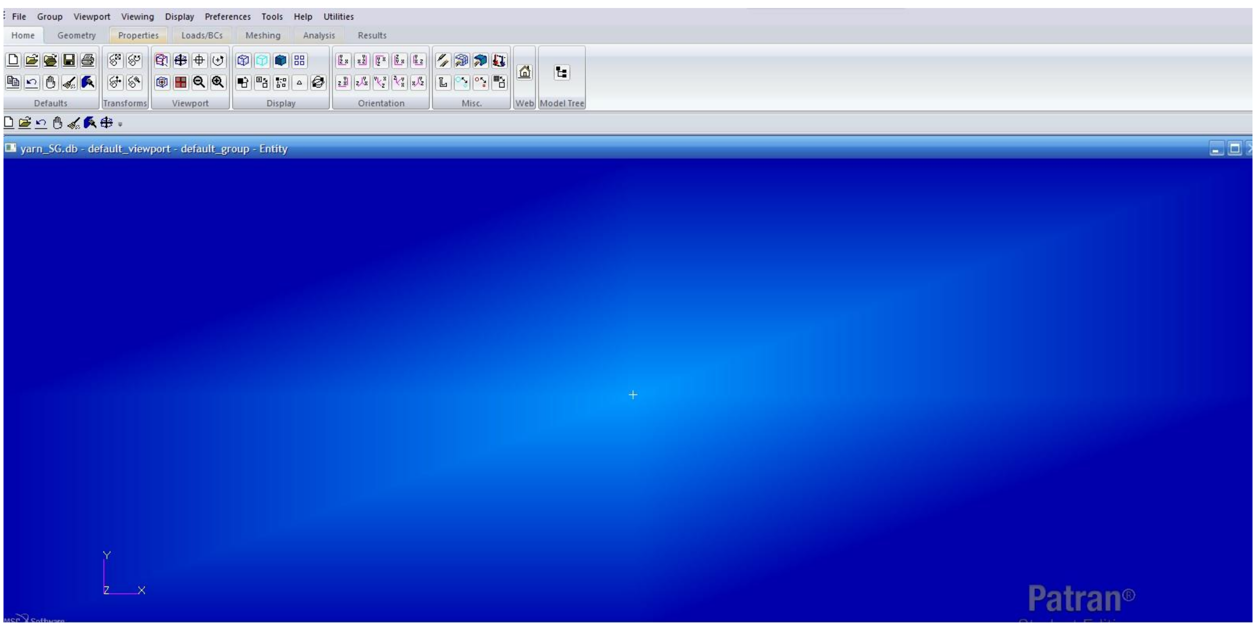

Fig. 3 New Patran database named Laminar_SG

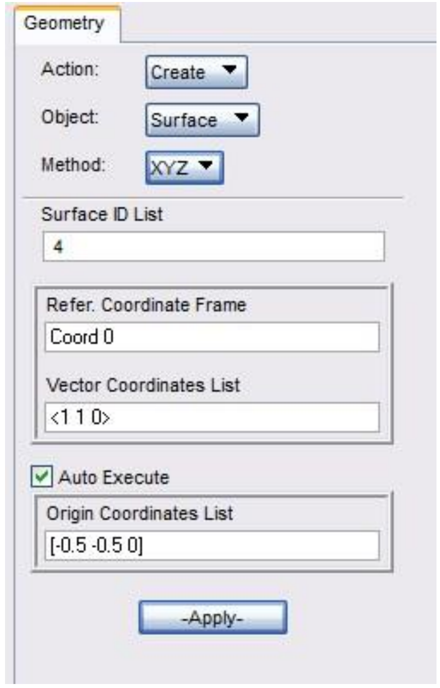

Fig. 4 Parameters for generating matrix of the SG

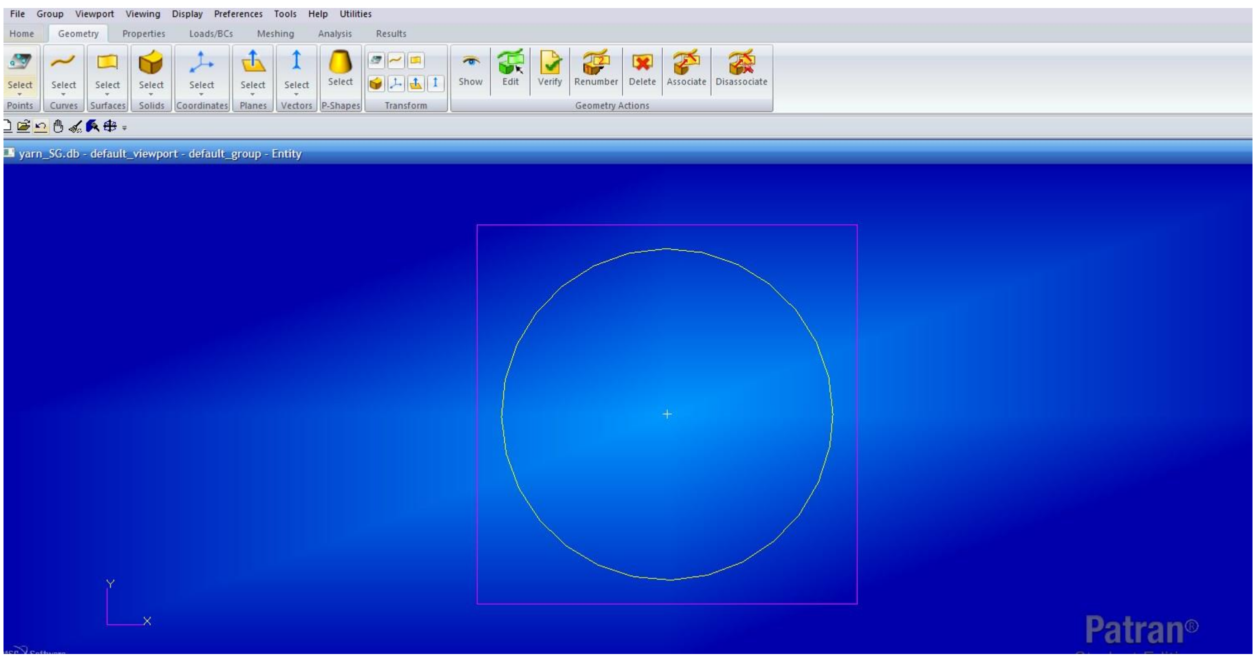

Fig. 5 Generating fiber inside the matrix

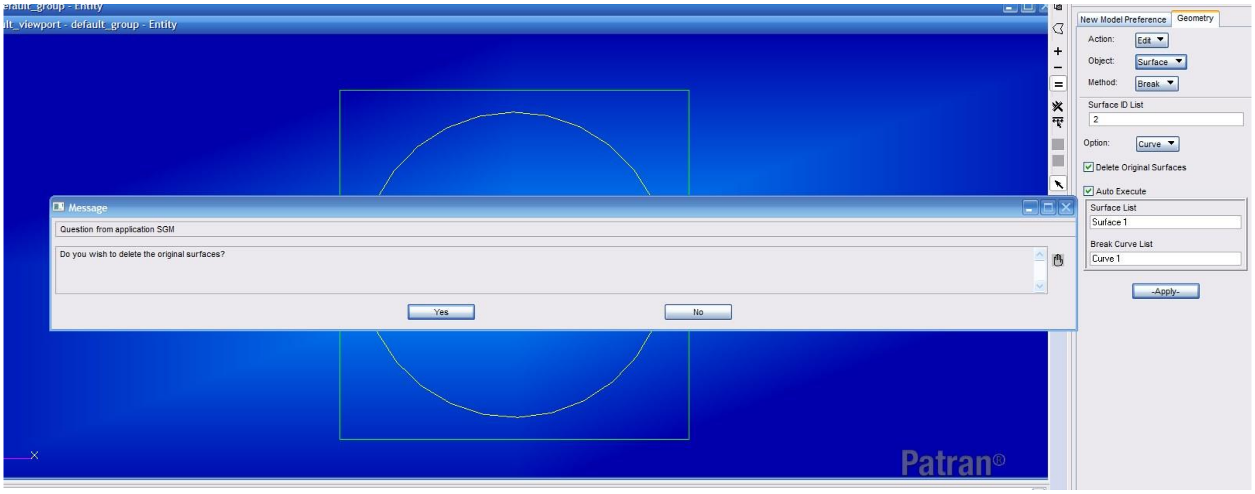

Fig. 6 Divide surface into fiber surface and matrix surface

Next, we need to define the material properties for fiber and matrix respectively. Click *Materials->Isotropic*, input Matrix as material name and click *Input Properties* and input parameters as shown in the Fig. 7 and click Apply. Click *Materials->3D Orthotropic*, input Fiber as material name and click *Input Properties* and input parameters as shown in the Fig. 8 and click Apply.

Select Element Properties Action: Create, Object: 2D and Type: 2D Solid. Give Matrix as Property Set Name, click *Input Properties* and select *matrix* properties click Ok. The click select *Application Region* and click on the surface corresponding to matrix material, click Ok and apply. Follow the same procedure to define fiber properties.

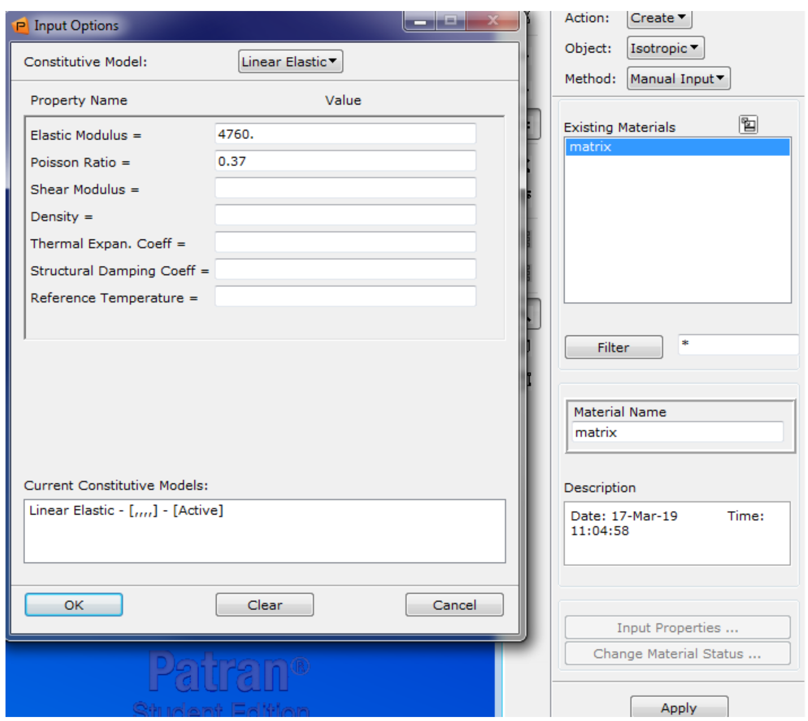

Fig. 7 Input matrix material properties

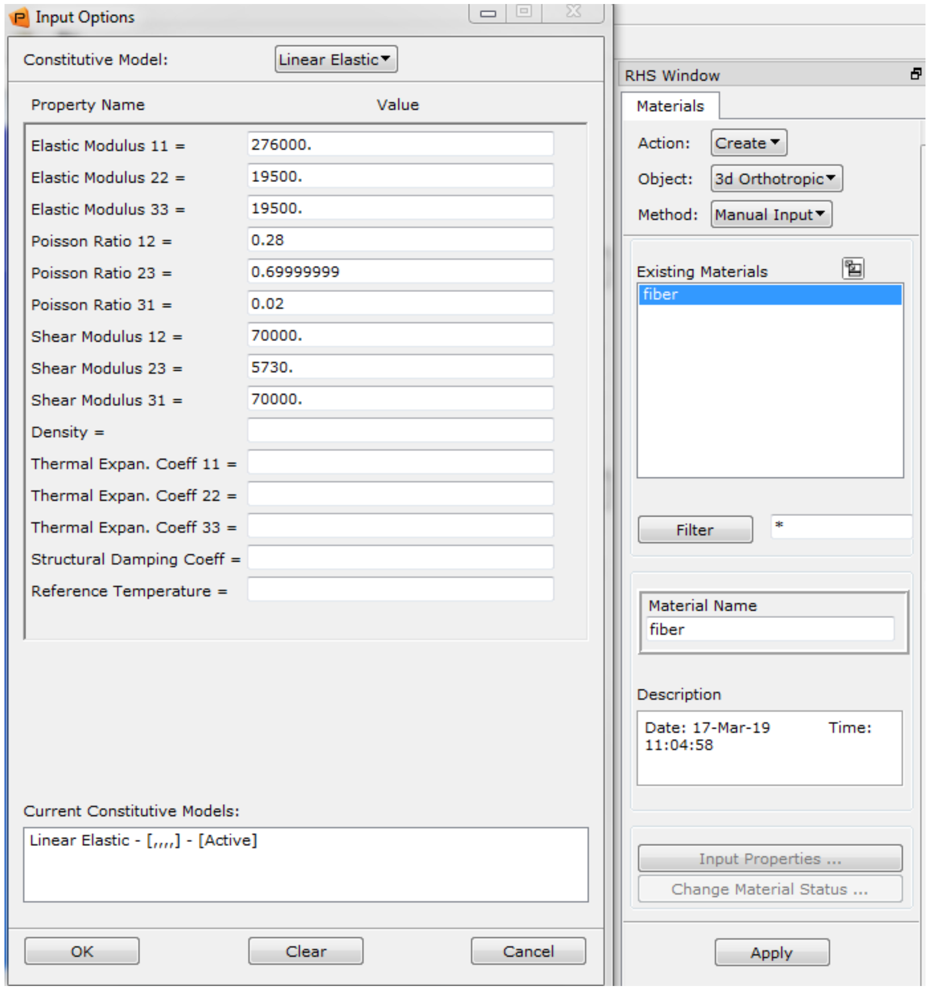

Fig. 8 Input fiber material properties

Next, we need to mesh the SG. Go to Mesh and assign mesh seed to each edge to make sure that a periodic mesh will be generated. In this example, each edge contains 20 seeds, and the circle contains 80 seeds. Go to Finite elements *Action: Create, Object: Mesh and Type: Surface*. Choose *Elem Shape: Tria, Mesher: Paver and Topology: Tria3* and select the surfaces corresponding to matrix and fiber. Keep all the other parameters as default values. Click apply, then the SG is meshed as shown in Fig. 9.

Now we will use the SC functions. Users need to install SC-Patran GUI as described in the installation manual, copy SwiftComp license file to the working directory, and type "!!input sc.pcl" in Patran command window to invoke all the SC related functions. Go to SwiftComp icon in the menu bar, and choose *Homogenization->Solid* as shown in Fig. 10 and select analysis type to be ThermoElastic, and keep all the other default parameters click apply. Note if the working directory contains a file with the same name, a warning message will be popup to ask if users want to overwrite the existed file. The results will be automatically popup as shown in Fig. 11.

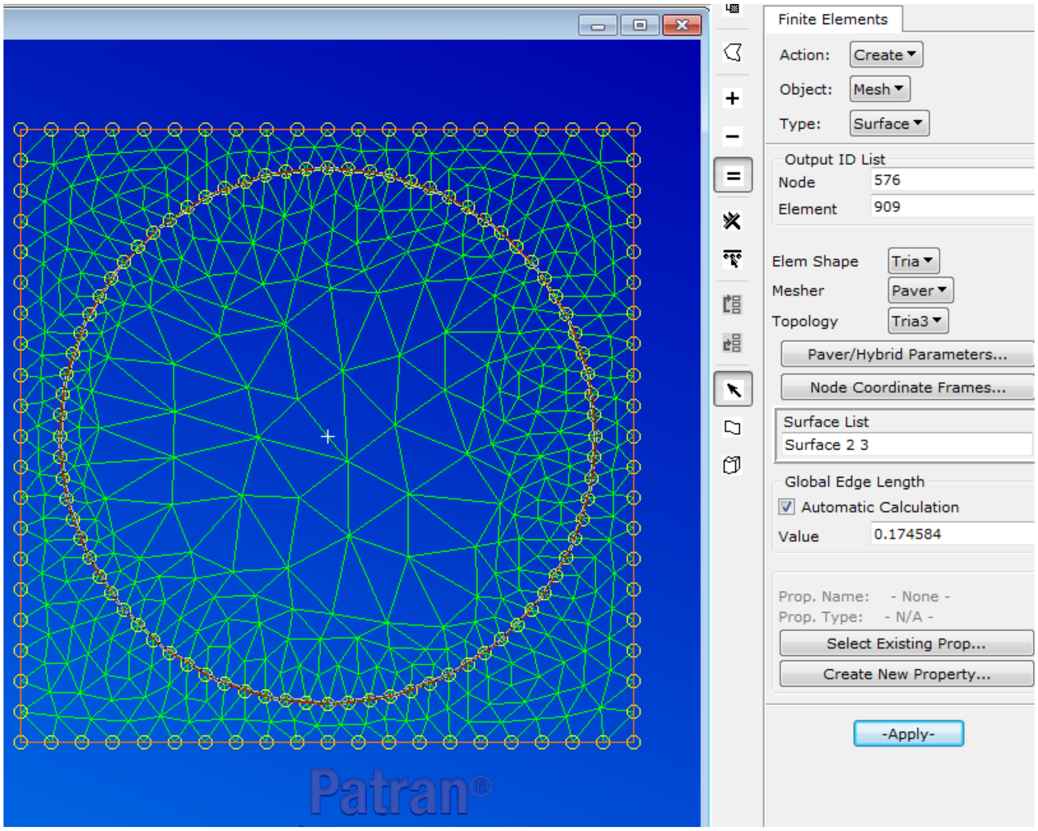

Fig. 9 Mesh the SG

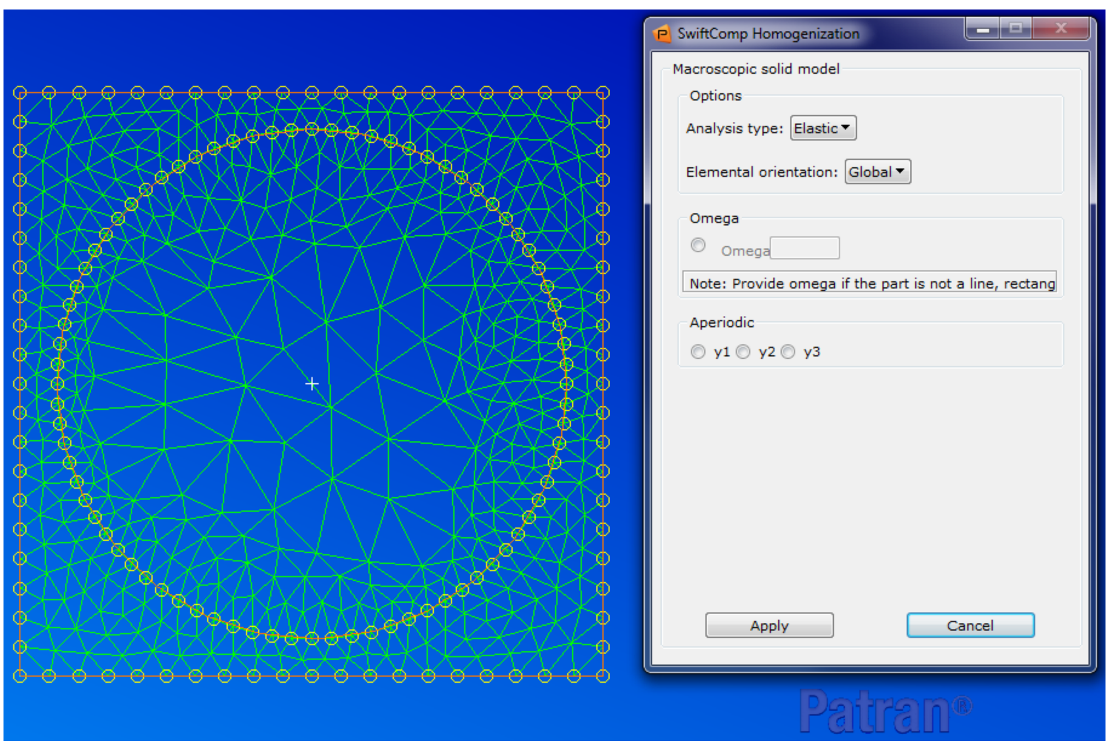

Fig. 10 Select SiwftComp homogenization solid model

```
Microscale.sc.k - Notepad
File  Edit  Format  View  Help
The Effective Stiffness Matrix
---------------------------------------------
  1.7277296E+05  8.6862739E+03  8.7033387E+03 -2.9516874E-02  0.0000000E+00  0.0000000E+00
  8.6862739E+03  1.7523062E+04  1.0280137E+04 -1.2792928E-01  0.0000000E+00  0.0000000E+00
  8.7033387E+03  1.0280137E+04  1.7524516E+04  1.3074564E-02  0.0000000E+00  0.0000000E+00
 -2.9516874E-02 -1.2792928E-01  1.3074564E-02  3.1003707E+03  0.0000000E+00  0.0000000E+00
  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  6.8065300E+03 -3.0462985E-02
  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00 -3.0462985E-02  6.8066997E+03

The Effective Compliance Matrix
---------------------------------------------
  5.9760400E-06 -1.8619673E-06 -1.8756708E-06 -1.2025185E-11  0.0000000E+00  0.0000000E+00
 -1.8619673E-06  8.7592778E-05 -5.0458482E-05  3.8093651E-09  0.0000000E+00  0.0000000E+00
 -1.8756708E-06 -5.0458482E-05  8.7594131E-05 -2.4692970E-09  0.0000000E+00  0.0000000E+00
 -1.2025185E-11  3.8093651E-09 -2.4692970E-09  3.2254207E-04  0.0000000E+00  0.0000000E+00
  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  1.4691774E-04  6.5752174E-10
  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  6.5752174E-10  1.4691408E-04

The Engineering Constants (Approximated as Orthotropic)
-----------------------------------------------------------
 E1   =   1.6733489E+05
 E2   =   1.1416466E+04
 E3   =   1.1416290E+04
 G12 =   6.8066997E+03
 G13 =   6.8065300E+03
 G23 =   3.1003707E+03
 nu12=   3.1157209E-01
 nu13=   3.1386516E-01
 nu23=   5.7605756E-01
```

Fig. 11 Results of solid homogenization analysis

Mesoscale homogenization

Once the effective yarn properties are obtained, we are ready for performing homogenization at macro-scale to get effective properties of woven laminar. The SG of 2 by 2 twill woven laminar is shown in Figure 12. The yarn width is 0.8 mm, yarn thickness is 0.1 mm and yarn spacing is 1 mm. The fabric thickness is 0.2 mm.

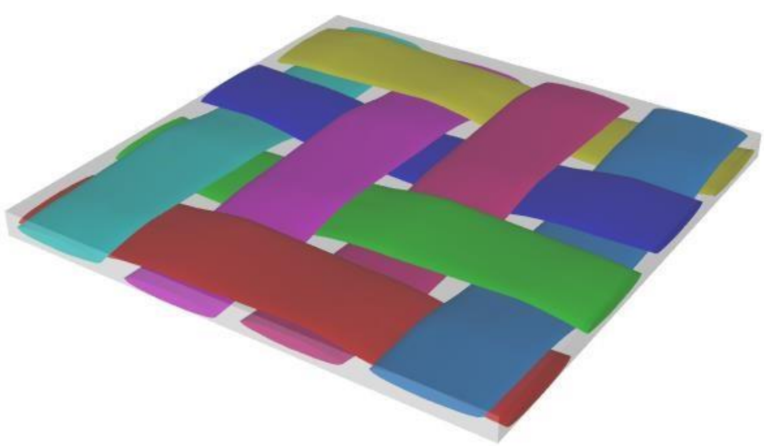

Fig. 12 2 by 2 twill woven SG

SwiftComp solid model is used for macro-scale homogenization, then import scmat (PCOMP+MAT8) function is used to create MAT8 properties in Patran.

Create a new database named Mesoscale, select *SwiftComp->Create woven composites->2 by 2 twill woven SG* as shown in Figure 13. The woven SG is created by TexGen4SC in the background, and users only need to input some parameters to define the SG as shown in Figure 14. The geometric information is given in this example. The woven composites using TexGen4SC is meshed using voxel mesh method to avoid distorted elements, and the voxel count needs to be defined for each direction in woven SG. In this example, we can keep all the default parameters, and click apply. TexGen4SC will be invoked in the background, and users will see the windows prompt as shown in Figure 15. Once the woven composites are generated, the prompt will be automatically closed. Note the woven SG is created in the sc file, and users need to use import sc file function to import the woven SG into Patran.

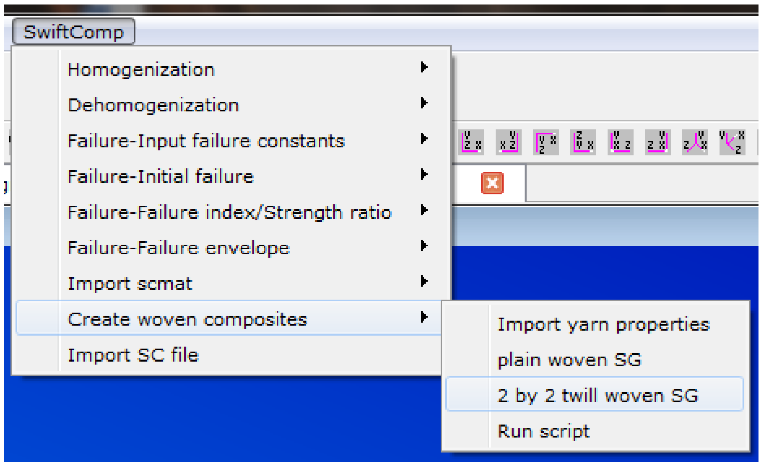

Fig. 13 Select woven type

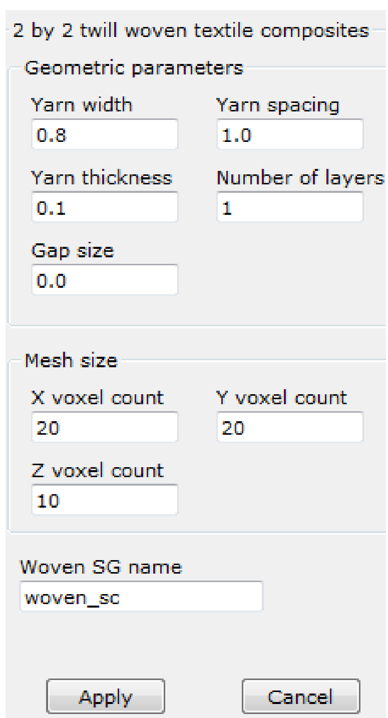

Fig. 14 Define woven geometric, material and mesh parameters

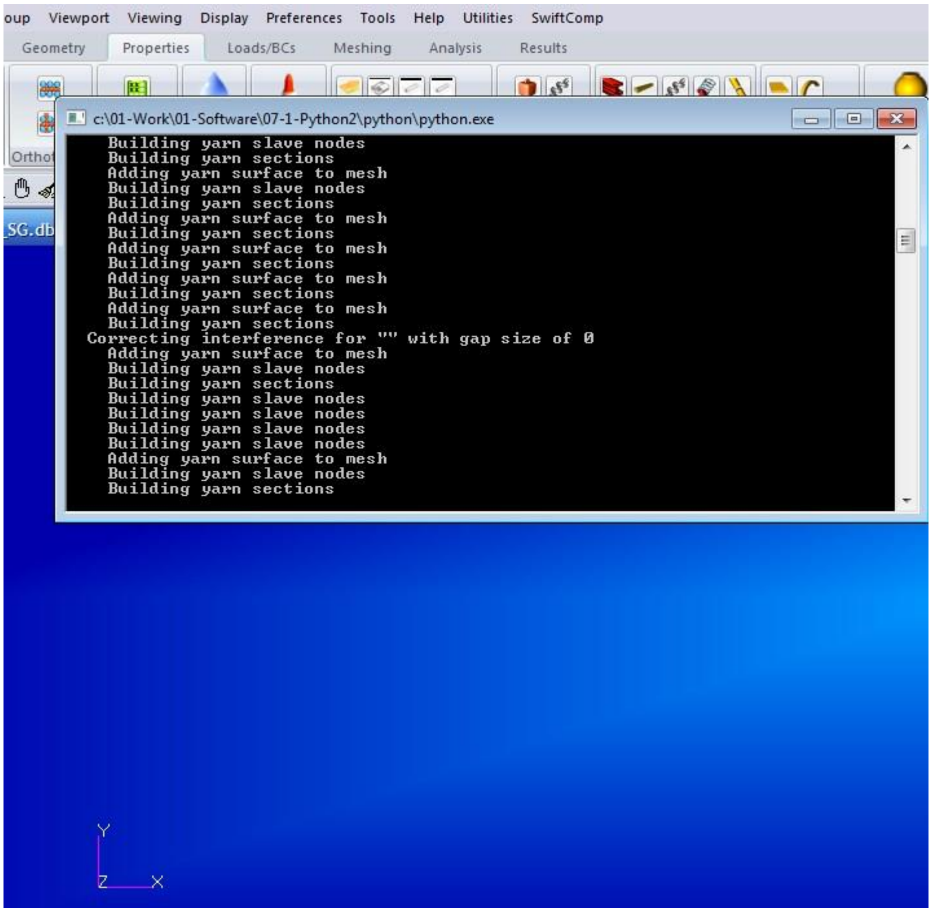

Fig. 15 Woven SG creation

Select *SwiftComp->Import SC file* as shown in Figure 16, the default sc file name is woven_sc.sc. The geometry and material properties of woven SG are imported into Patran database. The yarns of this SG is shown in Figure 17. Matrix and individual yarns are defined in different groups. In this case, there is one matrix group and 8 yarn groups as shown in Fig. 18. The multiple groups enable users to define different properties for different yarns. In this example, we will only consider just one set of yarn properties which are obtained from microscale analysis. The matrix properties are predefined, and users need to change the corresponding default properties to the user-define one.

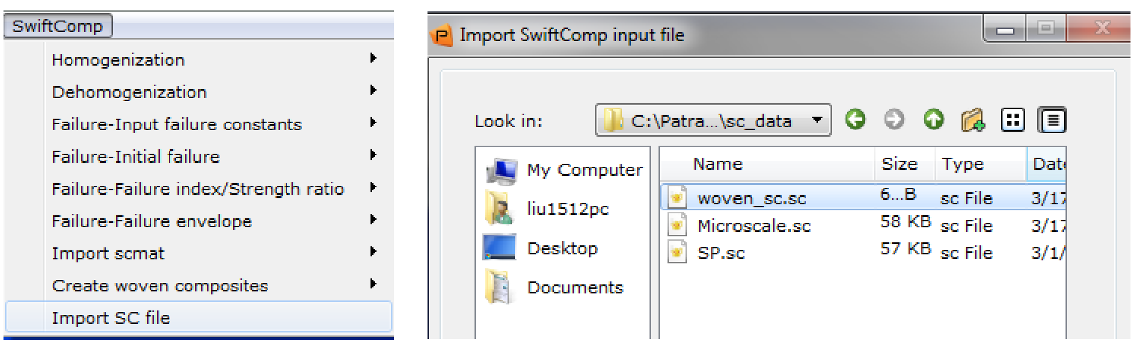

Fig. 16 Import woven SG into Patran

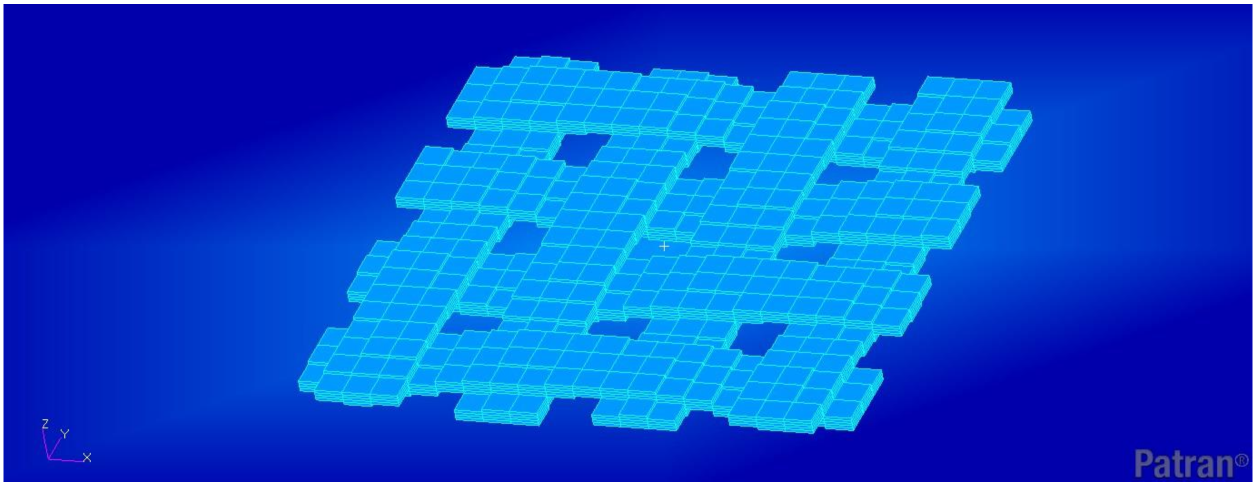

Fig. 17 Yarns of the woven SG in Patran

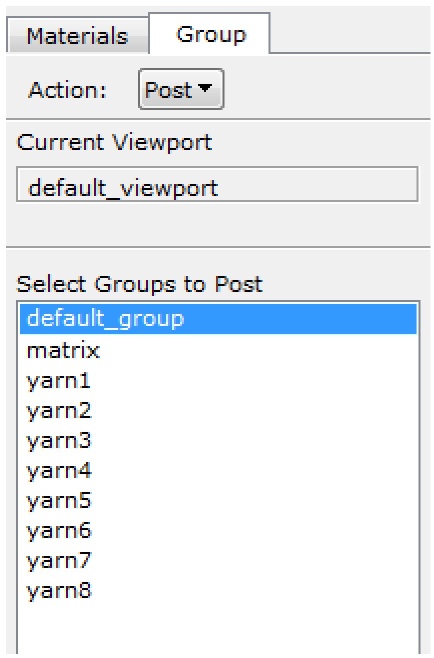

Fig. 18 Groups of matrix and yarns

The matrix properties are given in Fig.7. Note that the convention of the constitutive equation in Nastran and SwiftComp is different which means users cannot directly input the 6 by 6 stiffness in Fig. 11 into Patran. If we define G_{ij} as the stiffness matrix in Nastran and C_{ij} as the stiffness matrix in SwiftComp, we have the following relations in Table 1. Therefore, the yarn properties are changed to the properties given in Fig. 19.

Table 1. Relation between Nastran and SwiftComp in constitutive equation

$G_{11} = C_{11}$	$G_{12} = C_{12}$	$G_{13} = C_{13}$	$G_{14} = C_{16}$	$G_{15} = C_{14}$	$G_{16} = C_{15}$	$G_{22} = C_{22}$
$G_{23} = C_{23}$	$G_{24} = C_{26}$	$G_{25} = C_{24}$	$G_{26} = C_{25}$	$G_{33} = C_{33}$	$G_{34} = C_{36}$	$G_{35} = C_{34}$
$G_{36} = C_{35}$	$G_{44} = C_{66}$	$G_{45} = C_{46}$	$G_{46} = C_{56}$	$G_{55} = C_{44}$	$G_{56} = C_{45}$	$G_{66} = C_{55}$

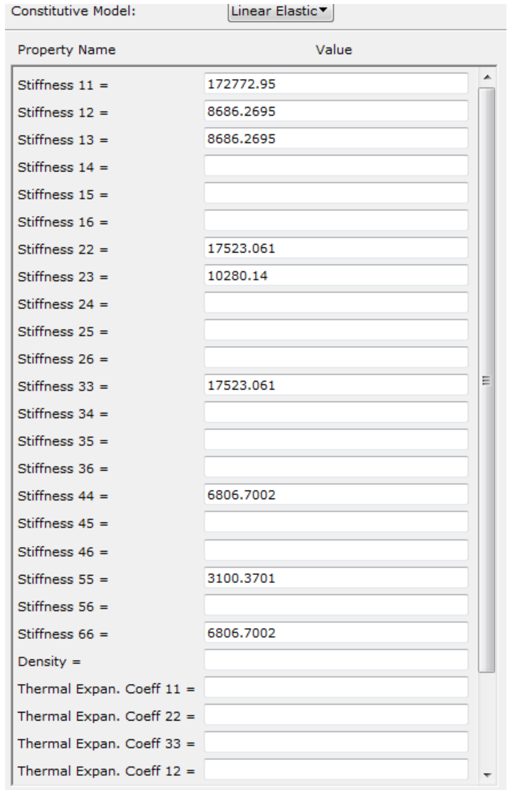

Fig. 18 Yarn properties

Select *SwiftComp->Homogenization->Solid* as shown in Figure 20, and click apply. Then, the effective constitutive information of solid model is automatically pop up.

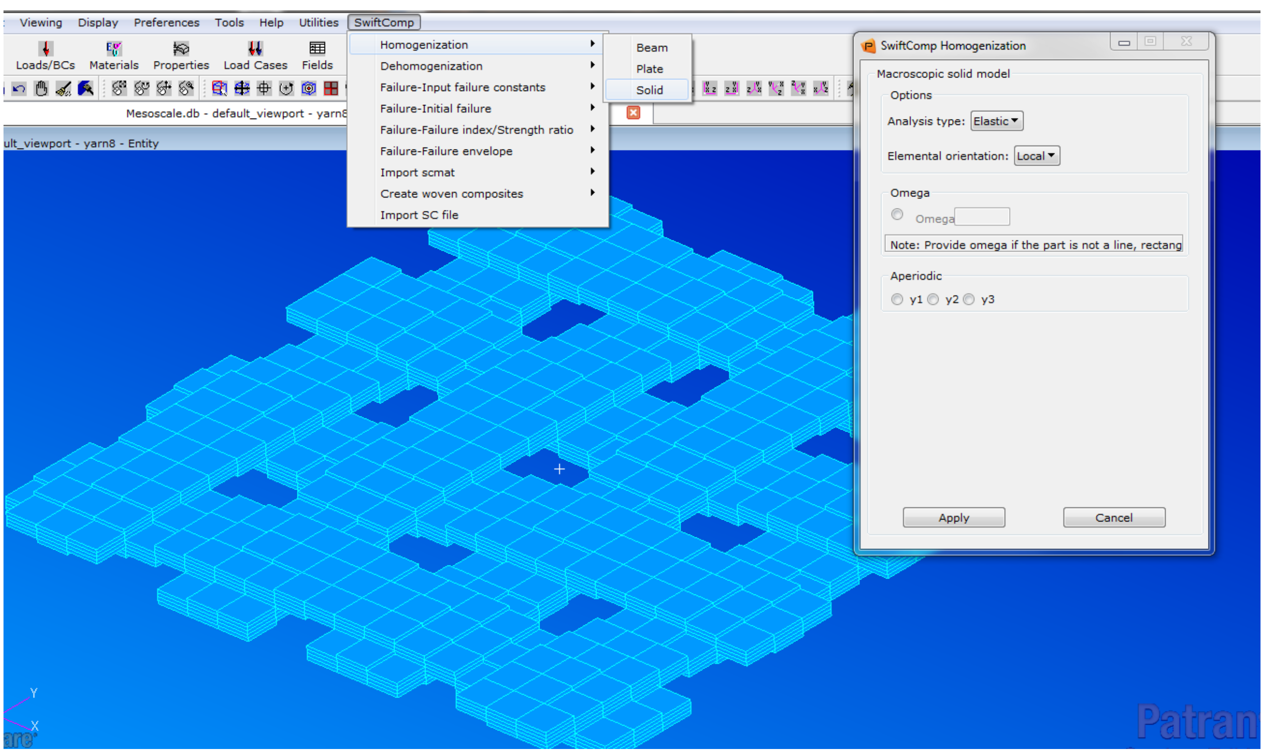

Fig. 20 Homogenization using SwiftComp solid model

```
The Effective Stiffness Matrix
--------------------------------------------
  5.0738030E+04  8.1656367E+03  7.0391837E+03 -1.6845505E-12 -6.0641416E-13  3.0170204E+01
  8.1656367E+03  5.0738049E+04  7.0391832E+03  1.6845115E-12  8.8408731E-13  3.0154597E+01
  7.0391837E+03  7.0391832E+03  1.2427646E+04  2.6487478E-13  3.4096543E-13  4.8598720E+00
 -1.6845505E-12  1.6845115E-12  2.6487478E-13  2.8959011E+03  1.3272589E+01 -2.8308591E-13
 -6.0641416E-13  8.8408731E-13  3.4096543E-13  1.3272589E+01  2.8959012E+03  4.8039996E-13
  3.0170204E+01  3.0154597E+01  4.8598720E+00 -2.8308591E-13  4.8039996E-13  3.7365480E+03

The Effective Compliance Matrix
--------------------------------------------
  2.1562272E-05 -1.9271279E-06 -1.1121550E-05  1.4637755E-20  6.3698368E-21 -1.4408408E-07
 -1.9271279E-06  2.1562263E-05 -1.1121544E-05 -1.2634723E-20 -5.5950225E-21 -1.4398590E-07
 -1.1121550E-05 -1.1121544E-05  9.3064522E-05 -8.4614185E-21 -9.8620206E-21  5.8509471E-08
  1.4637755E-20 -1.2634723E-20 -8.4614185E-21  3.4532292E-04 -1.5826953E-06  2.6360393E-20
  6.3698368E-21 -5.5950225E-21 -9.8620206E-21 -1.5826953E-06  3.4532291E-04 -4.4510785E-20
 -1.4408408E-07 -1.4398590E-07  5.8509471E-08  2.6360393E-20 -4.4510785E-20  2.6762895E-04

The Engineering Constants (Approximated as Orthotropic)
----------------------------------------------------------
 E1   =   4.6377301E+04
 E2   =   4.6377322E+04
 E3   =   1.0745233E+04
 G12 =   3.7365166E+03
 G13 =   2.8958403E+03
 G23 =   2.8958402E+03
 nu12=   8.9374989E-02
 nu13=   5.1578748E-01
 nu23=   5.1578743E-01


Effective Density =   0.0000000E+00
```

Fig. 21 Homogenization constitutive information for solid model

Macroscale analysis

This is the third step of using MSG to analyze woven laminated plate structures. We will perform macroscopic structural analysis. Open a new database and create a woven laminated plate structure as shown in Fig. 21. The user shall use consistent units in the SG and in the structural level database.

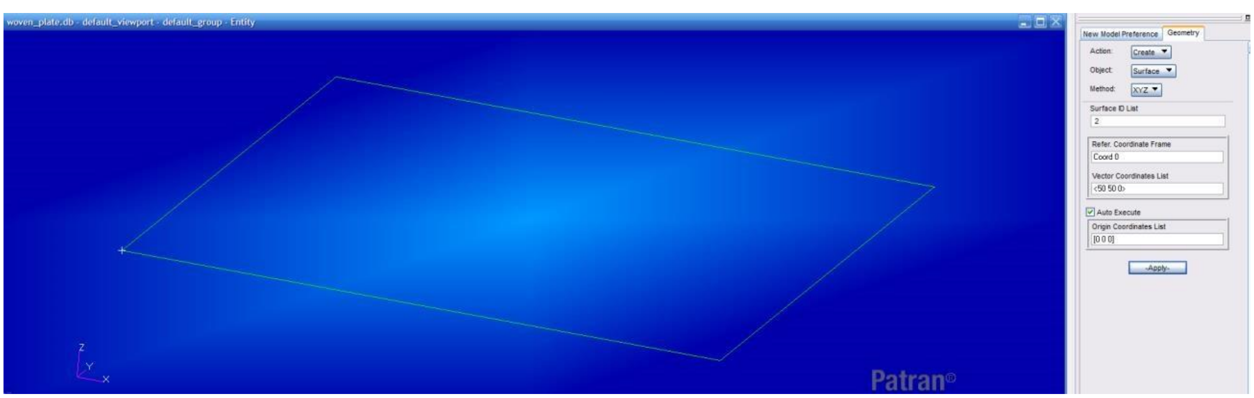

Fig. 22 Geometry of the laminated plate structure

In order to use PCOMP card in Nastran, we need to import MAT8 card from SwiftComp results. Users can import SC results file as shown in Fig. 23. The MAT8 import function can be found under Import scmat/Plate/PCOMP+MAT8. Then users can go to Material Properties, and check the homogenized 2D orthogonal material properties shown in Figure 24.

Users need to go to *Composite->Lamination* to define the layup and thickness of this laminated plate as shown in Figure 25, then users need to go to define Shell properties with laminate options as shown in Figure 26.

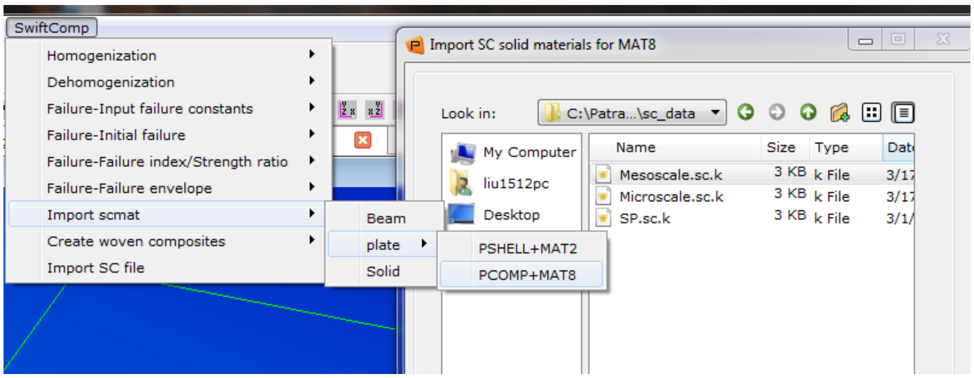

Fig. 23 Import laminar properties

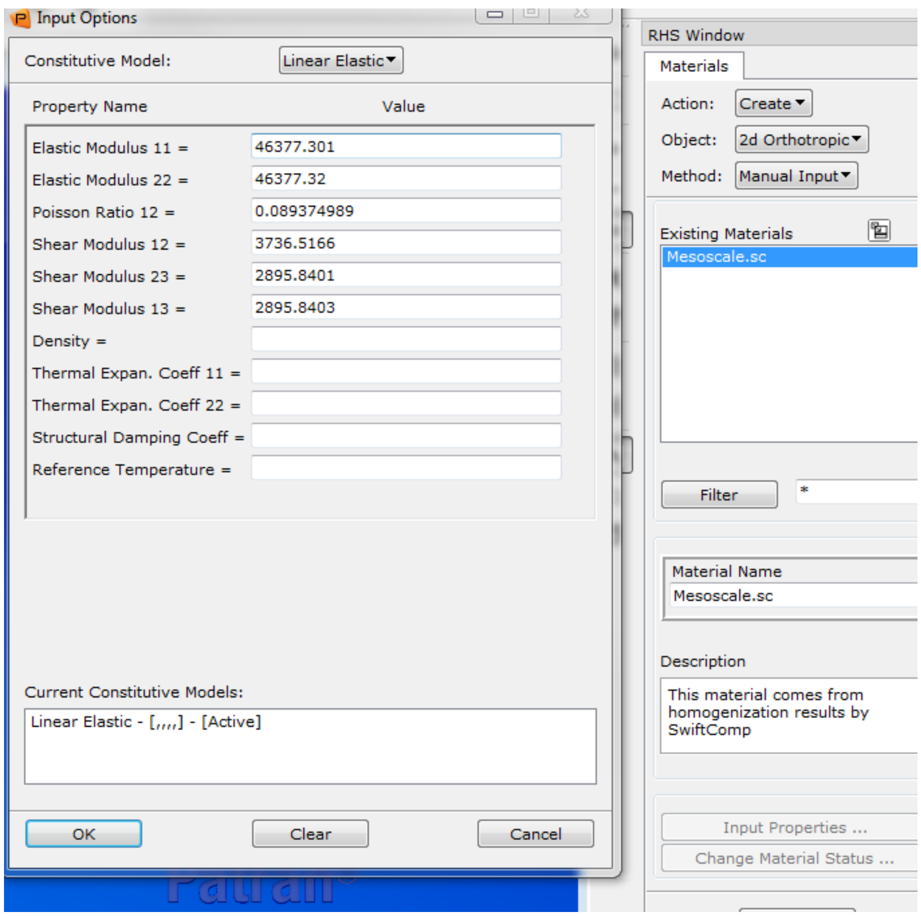

Fig. 24 Define material properties for PCOMP

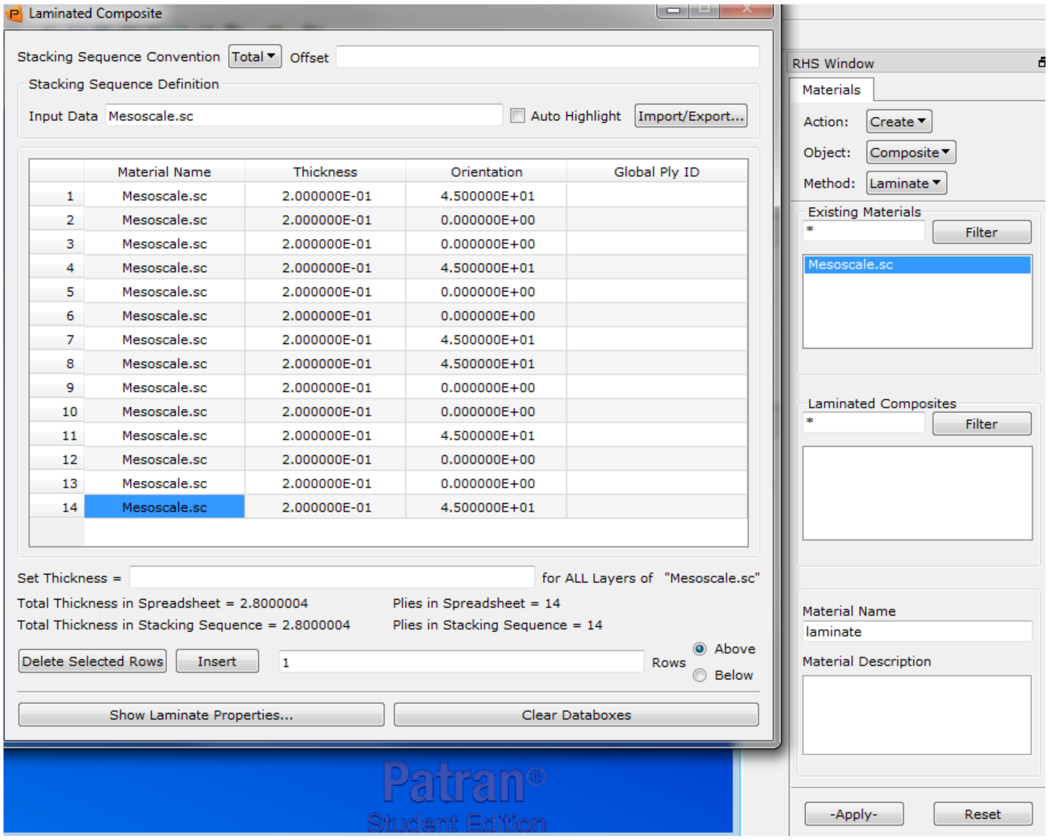

Fig.25 Define layup and thickness of laminated plate

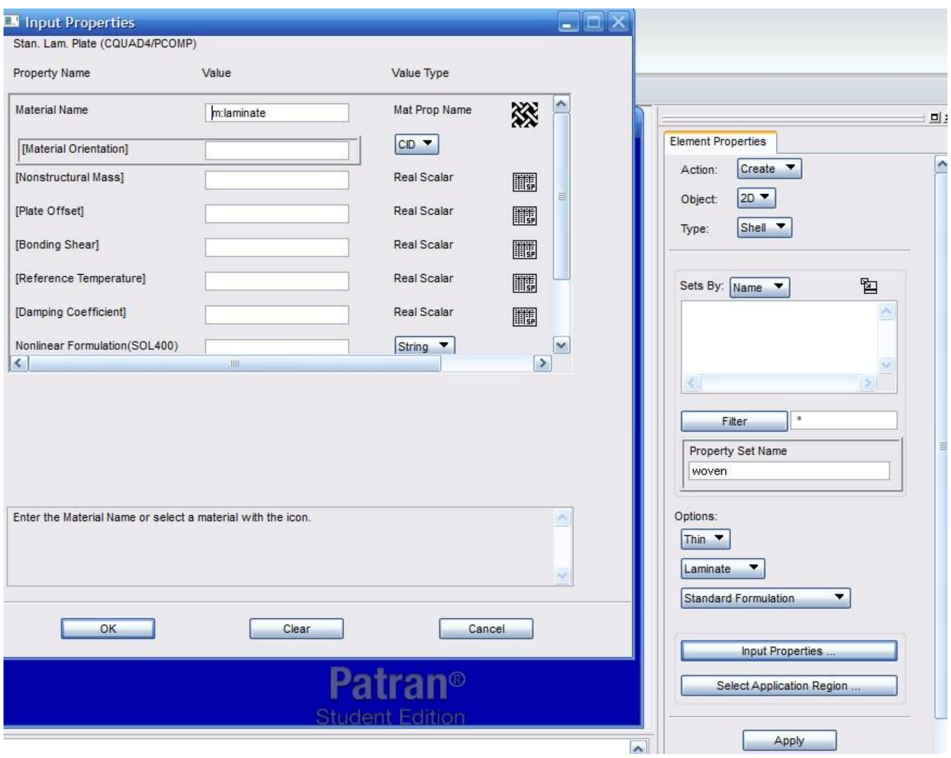

Fig. 26 Define shell elements with laminate options

Next, users can define the displacement boundary conditions and apply the pressure loading required in the problem statement. Mesh the model and submit the job. For those who are familiar with Patran/Nastran, these steps are very easy to complete, and therefore a detailed description of the modeling steps is not included in this manual. The screenshot for the model is given in Figure 27, and the typical displacements and stresses screenshots are given in Figure 28 and 29 just for reference.

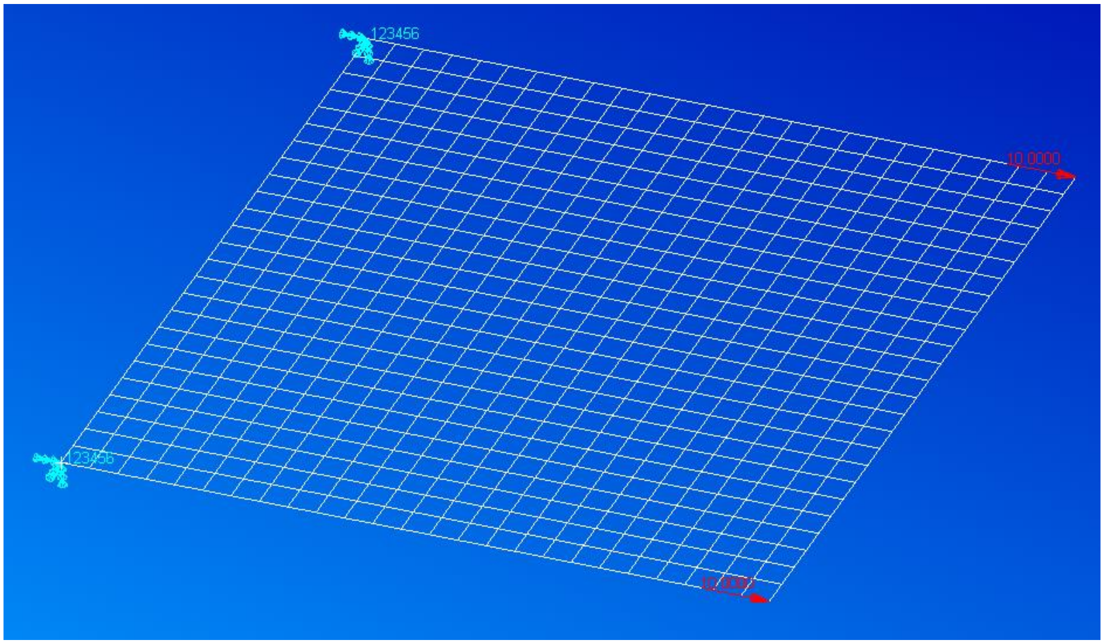

Fig. 27 Laminated plate model

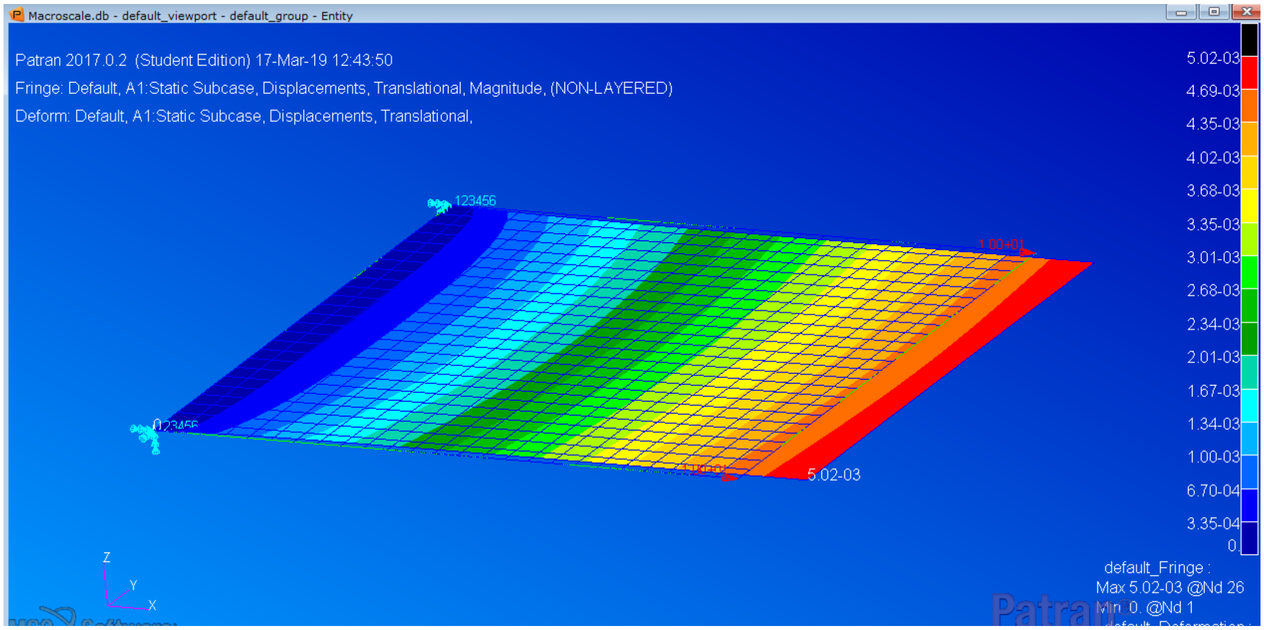

Fig. 28 Magnitude of displacement results

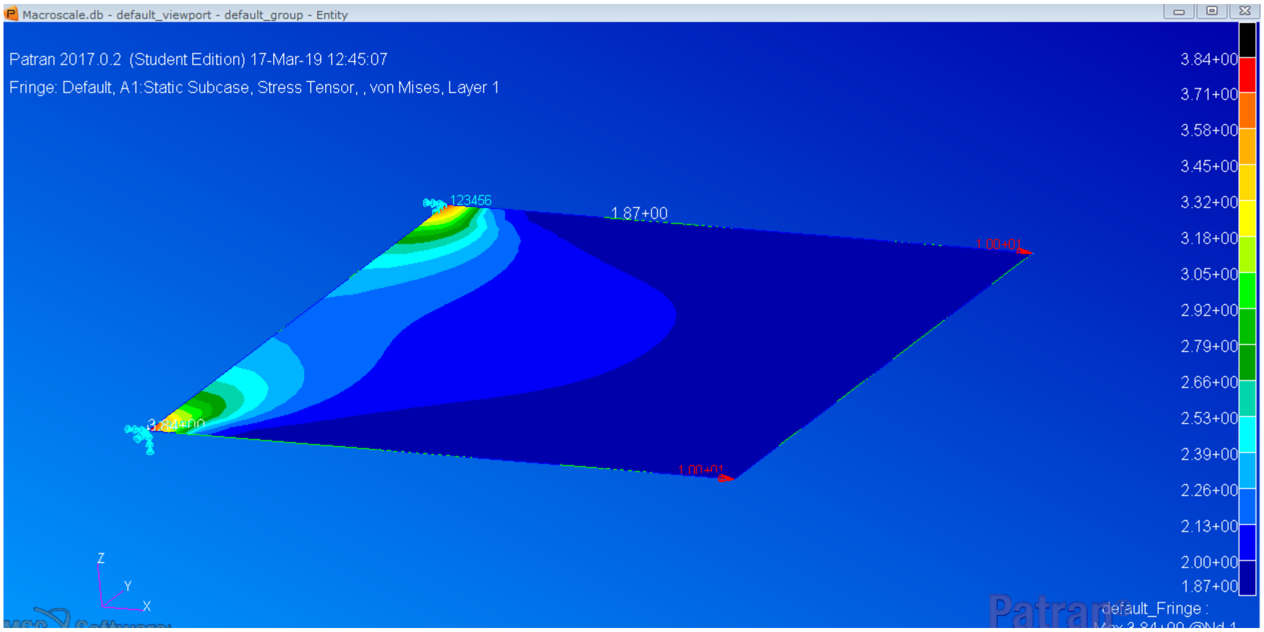

Fig. 29 von Mises stresses of layer 1