Design and Analysis of Representative Volume Element in respect of M50J Carbon Fiber Reinforce Polymer for Aerospace Application

[1]Akshay Kumar T S, [2]Dr. B. M. Rajaprakash,

[1]Department of Mechanical Engineering,
[1]University Visvesvaraya College of Engineering, Bengaluru, India.

Abstract: The structural materials to be used for aerospace applications should have good strength and modulus to withstand heavy loads and also should be light enough to fly/take-off. The material that best fits to these specifications is composite materials; Carbon Fiber Reinforced Polymers (CFRP) have been used in the aerospace application as carbon fibers have very high modulus and also withstand high loads. M50J is a type of carbon fiber that is reinforced with a resin which can be cured and used as CFRP structures. A representative volume element is designed and is analysed to evaluate the performances of this material in tension, compression and shear.

***Keyword* – Carbon fibers, Aerospace Materials, High Modulus Carbon Fiber, Analysis.**

I. Introduction

The term RVE or Representative Volume Element was coined by Rodney Hill, it refers to a sample that is structurally entirely typical of the whole mixture on average, and contains a sufficient number of inclusions for the apparent overall moduli to be effectively independent of the surface values of traction and displacement, so long as these values are macroscopically uniform.

RVE based methods break up analysis of a composite material into analyses at the local and global levels. The local level analysis models the micro-structural details to determine effective elastic properties. The local level analysis can also be used to calculate the relationship of the effective or average RVE strain to the local strain within the RVE. The global level analysis calculates the effective or average stress and strain within the equivalent homogeneous structure.

The following literature survey is made in order to provide some background information to RVE and also point out the relevance of the study.

S J Holister and N Kikuchi (1992), in this study, the elastic behaviour of a composite material based on the concept of a Representative Volume Element (RVE) is studied.The purpose of this paper was to compare homogenization and standard mechanics RVE based analyses for periodic porous composites with finite ratio of the RVE size to the global structural dimensions. From this study, we got to know that homogenization theory to study the RVE is better than the standard methods. The stress and strain tensor formulas for the RVE derived from the homogenization theory are as follows,

$$\overline{\sigma_{ij}} = \frac{1}{|Vrve|}\int_{Vrve} \sigma_{ij}(x)dv \text{ and } \overline{\varepsilon_{ij}} = \frac{1}{|Vrve|}\int_{Vrve} \varepsilon_{ij}(x)dv$$

where,$\overline{\sigma_{ij}}$, $\overline{\varepsilon_{ij}}$ are the average stresses and average strains and σ_{ij} and ε_{ij} are the local stresses and local strains in RVE and V_{RVE} is the volume of RVE.

From the analysis, the stresses and strains acting on each element is found out and the effective stresses and strains acting on the RVE is calculated using the homogenization theory. This average stress and strain is used to calculate the young's modulus. [1]

Zhun Liu et al, (2018), the theory of micro-mechanics of failure aims to explain the failure of continuous fiber reinforced composites by micro-scale analysis of stresses within each constituent material (such as fiber and matrix), and of the stresses at the interfaces between those constituents, calculated from the macro stresses at the ply level. From the above literature, micro mechanic study of continuous fibers can be understood and also the relation between macro and micro mechanics of the material can be studied. They used the tension and compression test to determine the strength of the matrix. The micro mechanical analysis of both the matrix and reinforcement is done in the dissertation work that is followed. [2]

Hadi Moussaddy, (2013), In this study, the author provides a first step towards optimization of the RVE determination methods for computing accurate effective properties and also explores new RVE definitions that yield smaller volumes and have lower determination costs, while yielding accurate effective properties. The second objective was evaluating the accuracy of analytical homogenization models for Randomly Oriented Fiber Reinforced Composites (ROFRC). The validation of the RVE determination methods would allow to valid modelling methods from the micro scale to the macro scale. Results of validated RVEs can be used as benchmarks for ideal representations of the composite microstructure. From this study, we could understand the importance of RVE in homogenization problems and also we know about the definitions of RVE. [3]

II. Methodology

The designing and analysis of the M50J carbon fiber reinforced polymer is executed on the softwares MSC Patran and Nastran. A micromechanical analysis is where the composite material is modelled and each constituent material's properties are given. The material is loaded and the mechanical properties are analytically calculated using the softwares MSC Patran and Nastran. The software is used to find out the stresses and strains at each element, the average stress and strain are calculated by using the homogenization theory.

Design

A RVE is modeled using the properties of the constituent materials. The dimensions for the RVE model are calculated using the volume fractions of the fiber with respect to that of the resin. The material properties of the constituent materials are as shown in table 1.

Table 1: Material Properties of M50J CFRP Prepreg system

Material	E_1 (in GPa)	E_2 (in GPa)	μ_{12}	G_{12} (in GPa)	P (in kg/m^3)
M50J Fiber	475	35	0.3	20	1880
Resin	4.05	-	0.396	1.45	1220

The weight fraction of the matrix is 34%, therefore

$$w_f = 34\% = 0.34$$
$$w_m = 1 - w_f$$
$$w_m = 1 - 0.34$$
$$w_m = 0.66 = 66\%$$
$$v_f = 55.36\% = 0.5536$$
$$v_m = 44.64\% = 0.4464$$

Analysis

The meshed RVE model is analysed on the software based on the boundary conditions applied for the model. The boundary conditions are applied on the basis of the different loads to be applied for different testing conditions. The testing conditions to be carried out are for tensile, compression and shear loading, the loads are applied on all the three directions i.e. X,Y and Z for tensile and compression loading whereas for shear loading only XY loading condition is applied. All the loads applied are displacement loads as the effective modulus can be calculated using the homogenization theory.

III. EXPERIMENTATION

The effective Young's modulus of the composite is calculated using the formulas of rule of mixture. The material properties of fibers and matrix are used and substituted into the formula.

$$w_f + w_m = 1 \quad \text{.... Equation 1}$$
$$v_f + v_m + v_v = 1 \quad \text{.... Equation 2}$$
$$E_1 = E_f v_f + E_m v_m \quad \text{.... Equation 3}$$
$$E_2 = \frac{E_f E_m}{(v_m * E_f) + (v_f * E_m)} \quad \text{.... Equation 4}$$
$$G_{12} = \frac{G_f G}{(v_m * G_f) + (v_f * G_m)} \text{.... Equation 5}$$
$$\rho_c = \frac{\rho_f \rho_m}{(w_m * \rho_f) + (w_f * \rho_m)} \text{.... Equation 6}$$
$$E_1 = E_f v_f + E_m v_m$$
$$E_1 = 475 * 0.5564 + 4.05 * 0.4336$$
$$\boldsymbol{E_1 = 266.04\ GPa}$$
$$E_2 = \frac{E_f E_m}{(v_m * E_f) + (v_f * E_m)}$$
$$E_2 = \frac{35 * 4.05}{(0.4336 * 35) + (0.5564 * 4.05)}$$
$$\boldsymbol{E_2 = 7.87\ GPa}$$
$$G_{12} = \frac{G_f G}{(v_m * G_f) + (v_f * G_m)}$$
$$G_{12} = \frac{20 * 1.45}{(0.4336 * 20) + (0.5564 * 1.45)}$$
$$\boldsymbol{G_{12} = 3.05\ GPa}$$
$$\rho_c = \frac{\rho_f \rho_m}{(w_m * \rho_f) + (w_f * \rho_m)}$$
$$\rho_c = \frac{1880 * 1220}{(0.4443 * 1880) + (0.5557 * 1220)}$$
$$\boldsymbol{\rho_c = 1587.9\ kg/m^3}$$

Design

The radius of the fiber in the RVE model is calculated to be approximately 0.42 mm and hence, the RVE is modelled with the fiber radius to be 0.42mm.

The RVE is modelled in a 2D geometry, this is meshed and then the mesh is extruded into a 3D model. The resin content by weight (weight fraction of resin) for both the prepreg system is 34%, using this, the volume fraction is calculated and the radius of the reinforcement is calculated.

$$V = \pi r^2 \text{h} \text{ .... Equation 7}$$

Considering V=V_f and h=1mm, r will be $r = \sqrt{\frac{V}{\pi h}}$

Therefore, $r = \sqrt{\frac{0.5536}{\pi}}$

$$r = 0.419 \cong 0.42\ mm$$

Analysis

The model is paver meshed as it can be used to mesh on any type of surfaces and also it can produce both quad and tria elements ; the elements are 3D solid elements and 3D solid elements maybe based on triangles (tria elements) and quads (quad elements) called TET and HEX respectively. HEX elements are used in the meshing of the RVE model; there are totally 6980 HEX elements. The meshed model is as shown in fig. 1

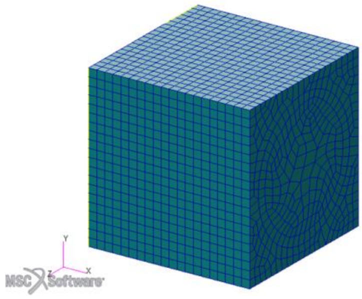

Fig. 1: The meshed RVE model.

The boundary conditions are applied to the meshed model, where one of the faces is loaded and another face is constrained in all directions and degrees of freedom.

For tensile loading, displacement load is applied in the fiber direction, while the face opposite to the loaded face is constrained in all directions. In fig. 2 we can see that the face in X-direction is applied with a displacement load of 1 unit, whereas the face opposite to this is fixed in all directions.

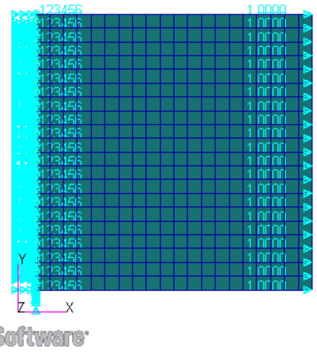

Fig. 2: Displacement load in the direction of the fiber (X-direction, Tensile Loading)

Similarly displacement loads are applied in transverse direction of the fibers, the displacement is applied in the Y direction and Z direction and the opposite faces of the respective faces are constrained in all directions. The boundary conditions for Y and Z directions are showed in fig. 3(a) and fig. 3(b) respectively.

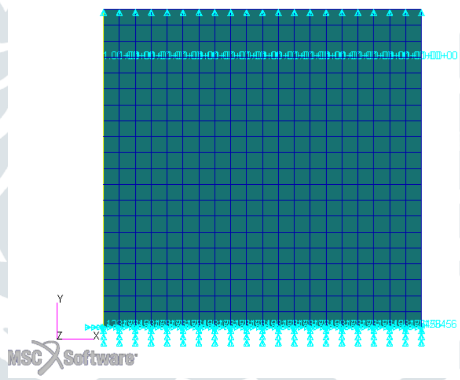

Fig. 3: (a.)Displacement load in the transverse direction (Y-direction, Tensile Loading)

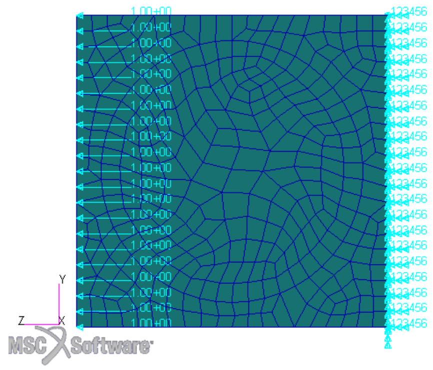

Fig. 3: (b.)Displacement load in the transverse direction (Z-direction, Tensile Loading)

Compression loading is similar to tensile loading, but the load is applied in the opposite direction as in tensile condition, the face opposite to the loaded face is constrained in all directions. In fig. 4 we can see that the face in the negative X-direction (negative direction for compression loading) is applied with a displacement load of 1 unit, whereas the face opposite to this is fixed in all directions.

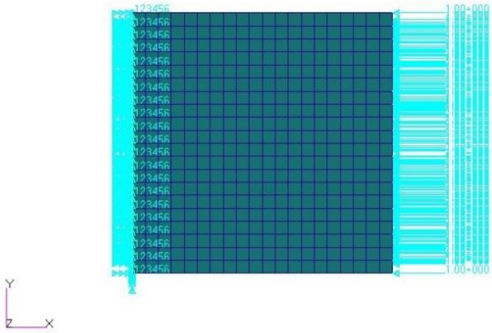

Fig. 4: Displacement load in the direction of the fiber (X-direction, Compression Loading)

Similarly displacement loads are applied in transverse direction of the fibers, the displacement is applied on the face in the negative Y direction and negative Z direction and the opposite faces of the respective faces are constrained in all directions. The boundary conditions for Y and Z directions are showed in fig. 5(a) and fig. 5(b) respectively.

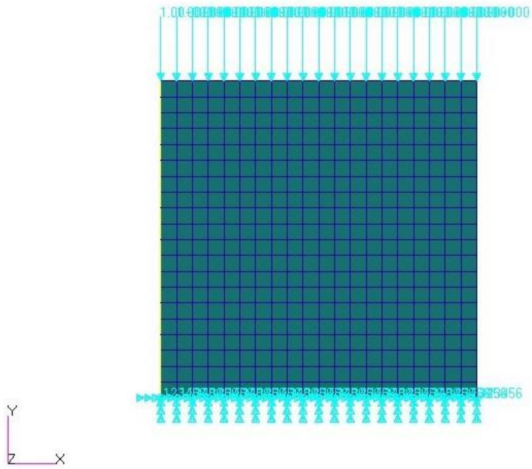

Fig. 5: (a.)Displacement load in the transverse direction (Y-direction, Compression Loading)

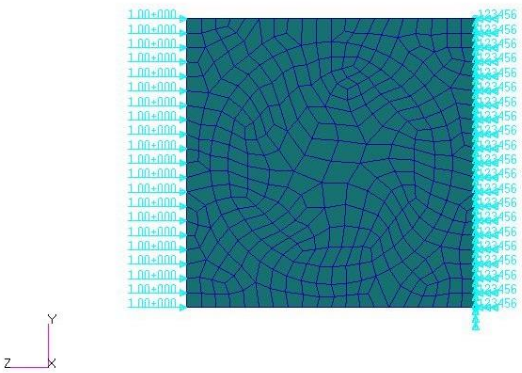

Fig. 5: (b.)Displacement load in the transverse direction (Z-direction, Compression Loading)

In shear loading, the displacement is applied in one direction at one of the faces on the corresponding direction and the other face opposite to this face is constrained in all directions. In fig 6, we can see that the displacement loading is in the X direction on a face on the Y direction, and the opposite face is constrained.

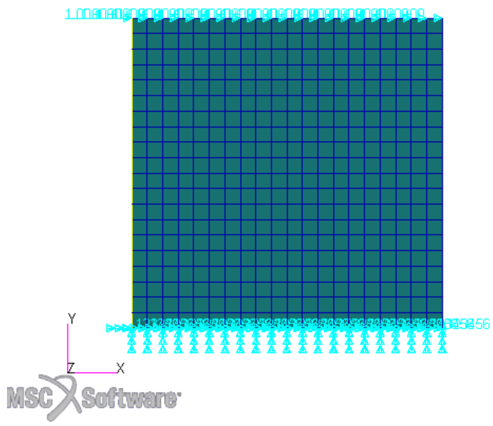

Fig. 6: XY Shear loading condition (displacement)

IV. Results and Discussion

4.1 Tensile Loading

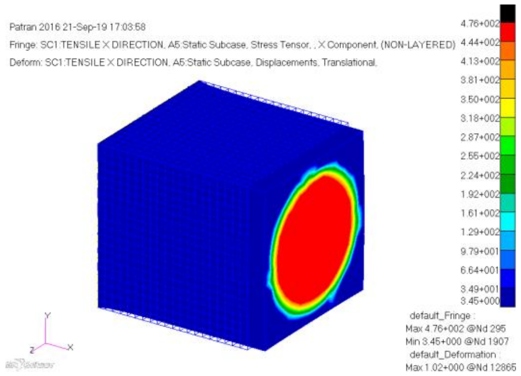

Fig. 7: Stress tensor X-direction - Force (Isometric view)

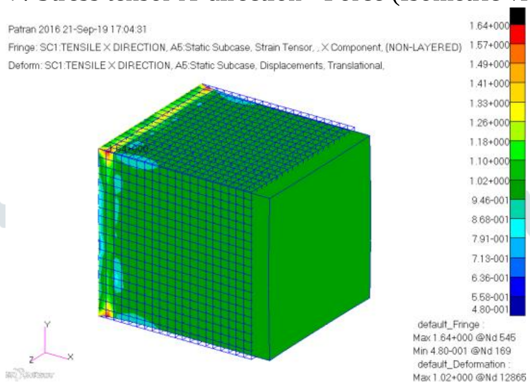

Fig. 8: Strain tensor X-direction - Force (Isometric view)

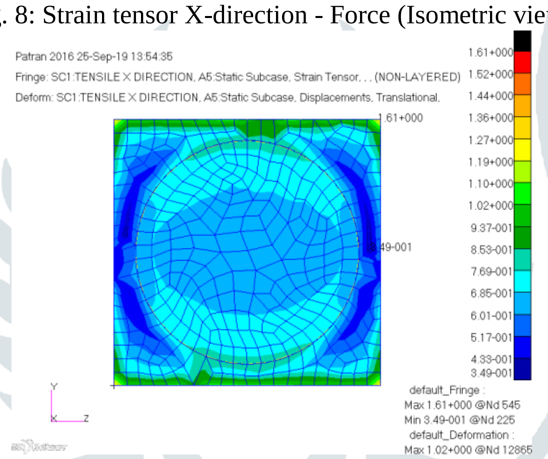

Fig. 9: Strain tensor X-direction (Strains acting on the rear side of the RVE)

When a displacement load is applied on the RVE model in the fiber direction (X-direction), the stress in the material are concentrated more on the fibers as shown in figure 7.

The strains in the model is as shown in figures 8 and 9, the strains are almost uniform through the model except for the matrix at the rear where the model was constrained in all directions. The stresses and strains of each element are recorded from the analysis as shown in Table 2 (a).

Table 2: (a) Stress and Strains in Each Element When Displacement is Applied in X Direction

		Stress(GPa)		Strain	
Element	Volume (mm^3)	X	X*Volume	X	X*Volume
350	8.43E-05	5.915784	4.98E-04	0.917549	7.73E-05
351	0.000104	5.924603	6.15E-04	0.912825	9.48E-05
352	0.000128	5.792768	7.43E-04	0.893059	1.14E-04
353	0.000175	5.655126	9.91E-04	0.867726	1.52E-04
354	0.000163	5.593449	9.13E-04	0.865113	1.41E-04
355	0.000144	5.576685	8.05E-04	0.863561	1.25E-04
356	0.000145	5.447426	7.92E-04	0.856754	1.25E-04
357	0.000177	5.306689	9.39E-04	0.842742	1.49E-04
358	0.000175	5.095148	8.91E-04	0.830709	1.45E-04
359	0.000142	5.063494	7.20E-04	0.848037	1.21E-04
-	-	-	-	-	-
-	-	-	-	-	-

-	-	-	-	-	-
7320	0.000154	475.411377	9.28E-02	1.001018	1.95E-04
7321	0.000255	475.389832	6.88E-02	1.000969	1.45E-04
7322	0.00023	475.454468	1.13E-01	1.001118	2.39E-04
7323	7.30E-05	475.428253	8.49E-02	1.001053	1.79E-04
7324	7.14E-05	475.446594	8.26E-02	1.00109	1.74E-04
7325	8.05E-05	475.446503	7.30E-02	1.001076	1.54E-04
7326	0.000215	475.468018	1.21E-01	1.00115	2.56E-04
7327	0.000147	475.458191	1.09E-01	1.001117	2.30E-04
7328	0.000133	475.291931	3.47E-02	1.000746	7.31E-05
7329	0.000109	475.079163	3.39E-02	1.000292	7.14E-05
∑V	1.00E+00	∑(stress*vol)	2.65E+02	∑(strain*vol)	1.00E+00

The data obtained from the analysis is used to calculate the average stress and strains. The Young's modulus is calculated using the average stress and strain as shown in Table 2 (b).

$$Average\ Stress = \frac{\sum(\text{stress} * \text{vol})}{\sum \text{V}}$$

$$Average\ Stress = \frac{2.65\text{E} + 02}{1.00\text{E} + 00}$$

$$Average\ Stress = \mathbf{2.65E + 02}$$

$$Average\ Streain = \frac{\sum(\text{strain} * \text{vol})}{\sum \text{V}}$$

$$Average\ Streain = \frac{1.00\text{E} + 00}{1.00\text{E} + 00}$$

$$Average\ Streain = \mathbf{1.00E + 00}$$

Table 2: (b) Young's Modulus in the Fiber Direction (E_1)

Average Stress in GPa	265.1935
Average Strain	1
E1 (Ex) in GPa	265.1935

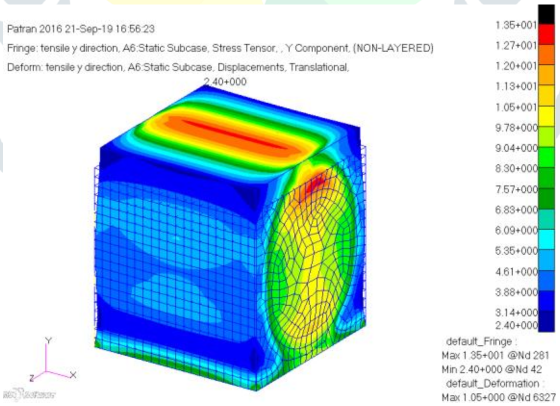

Fig. 10: (a) Stress tensor Y-direction (Isometric view)

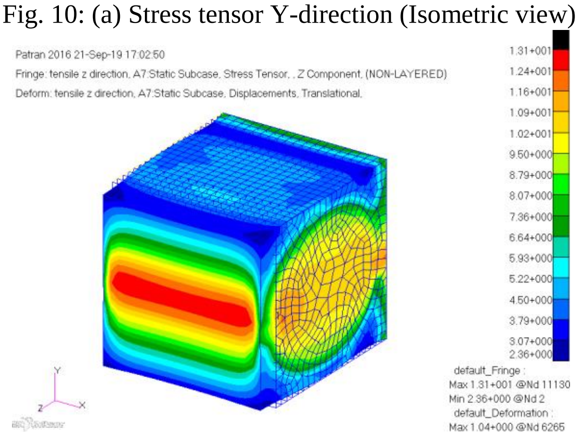

Fig. 10: (b) Stress tensor Z-direction (Isometric view)

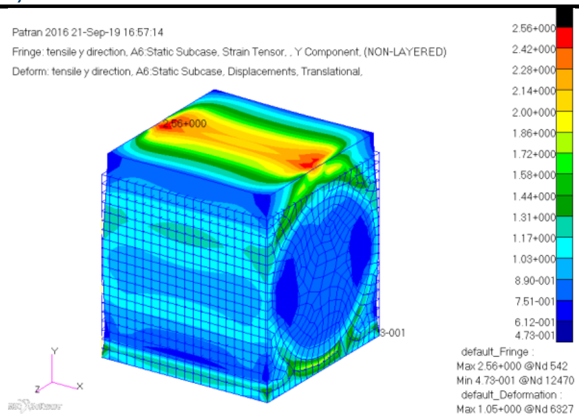

Fig. 11: (a) Strain tensor Y-direction (Isometric view)

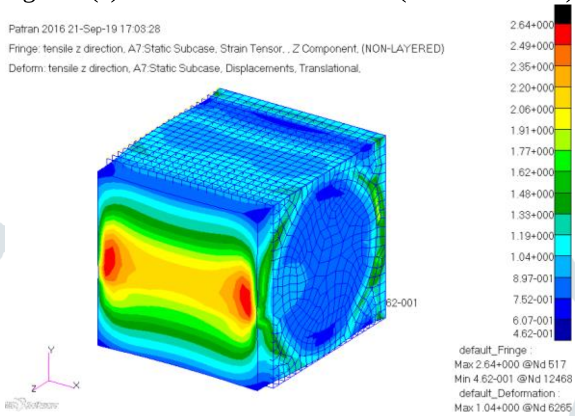

Fig. 11: (b) Strain tensor Z-direction (Isometric view)

The displacement load in the transverse direction is applied in the Y-direction and Z-direction. The stresses can be found through the model in the direction in which the displacement load is applied, the stress is maximum at the interface of the fiber and the matrix as shown in figure 10(a) and (b) for Y and Z direction respectively.

It can be seen that from the figure 11(a) and (b), the stresses are high through only the matrix in the load direction, and it is maximum near the surface of the model. The stress and strains acting in each element in Y and Z directions are as shown in Table 3(a) and 3(b) respectively. The average stress and strain and the Young's modulus are as shown in Table 3(c).

Table 3: (a) Stress and Strains in Each Element When Displacement is Applied in Y Direction

		Stress(GPa)		Strain	
Element	Volume (mm^3)	Y	Y*Volume	Y	Y*Volume
350	8.43E-05	10.586232	8.92E-04	1.802969	1.52E-04
351	0.000104	10.357267	1.08E-03	1.835768	1.91E-04
352	0.000128	9.698721	1.24E-03	1.835548	2.35E-04
353	0.000175	9.000152	1.58E-03	1.809105	3.17E-04
354	0.000163	8.268178	1.35E-03	1.79052	2.92E-04
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
7324	7.14E-05	9.410087	2.16E-03	0.784158	1.80E-04
7325	8.05E-05	10.800133	7.88E-04	0.899875	6.57E-05
7326	0.000215	11.180834	7.98E-04	0.931992	6.65E-05
7327	0.000147	11.121047	8.95E-04	0.926888	7.46E-05
7328	0.000133	10.148573	2.18E-03	0.845697	1.82E-04
7329	0.000109	9.977265	1.47E-03	0.831413	1.22E-04
∑V	1.00E+00	∑(stress*vol)	8.11E+00	∑(strain*vol)	1.00E+00

The data obtained from the analysis is used to calculate the average stress and strains.

$$Average\ Stress = \frac{\sum(\text{stress} * \text{vol})}{\sum V}$$

$$Average\ Stress = \frac{8.11E+00}{1.00E+00}$$

$$Average\ Stress = \mathbf{8.11E+00}$$

$$Average\ Streain = \frac{\sum(\text{strain} * \text{vol})}{\sum V}$$

$$Average\ Streain = \frac{1.00\text{E}+00}{1.00\text{E}+00}$$
$$Average\ Streain = \mathbf{1.00E+00}$$

Table 3: (b) Stress and Strains in Each Element When Displacement is Applied in Z Direction

		Stress(GPa)		Strain	
Element	Volume (mm^3)	Z	Z*Volume	Z	Z*Volume
350	8.43E-05	3.817984	3.22E-04	0.778497	6.56E-05
351	0.000104	4.110198	4.27E-04	0.857872	8.91E-05
352	0.000128	4.456331	5.71E-04	0.960785	1.23E-04
353	0.000175	4.823646	8.46E-04	1.07935	1.89E-04
354	0.000163	5.591079	9.12E-04	1.249363	2.04E-04
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
7324	7.14E-05	10.271081	2.36E-03	0.855924	1.97E-04
7325	8.05E-05	8.898094	6.50E-04	0.741508	5.41E-05
7326	0.000215	8.611942	6.15E-04	0.717662	5.12E-05
7327	0.000147	8.749415	7.04E-04	0.729118	5.87E-05
7328	0.000133	9.645565	2.07E-03	0.803797	1.73E-04
7329	0.000109	9.616299	1.41E-03	0.801358	1.18E-04
∑V	1.00E+00	∑(stress*vol)	8.11E+00	∑(strain*vol)	1.00E+00

The data obtained from the analysis is used to calculate the average stress and strains. The Young's modulus is calculated using the average stress and strain as shown in Table 3(c).

$$Average\ Stress = \frac{\sum(\text{stress} * \text{vol})}{\sum \text{V}}$$
$$Average\ Stress = \frac{8.11\text{E}+00}{1.00\text{E}+00}$$
$$Average\ Stress = \mathbf{8.11E+00}$$
$$Average\ Streain = \frac{\sum(\text{strain} * \text{vol})}{\sum \text{V}}$$
$$Average\ Streain = \frac{1.00\text{E}+00}{1.00\text{E}+00}$$
$$Average\ Streain = \mathbf{1.00E+00}$$

Table 3: (c) Young's Modulus in the Transverse Direction (E_2)

	Y-direction	Z-direction
Average Stress in GPa	8.11307	8.10877
Average Strain	0.999974	0.999885
E_2 in GPa	8.11327	8.109709

4.2 Compression Loading

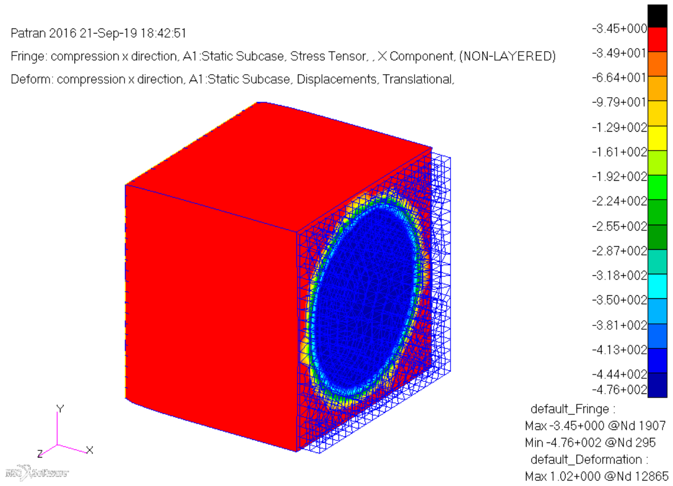

Fig. 12: Stress tensor X-direction (Isometric view)

When a displacement load is applied on the RVE model in the fiber direction (negative X-direction), the stress in the material are concentrated more on the matrix than on the fiber as shown in figure 12.

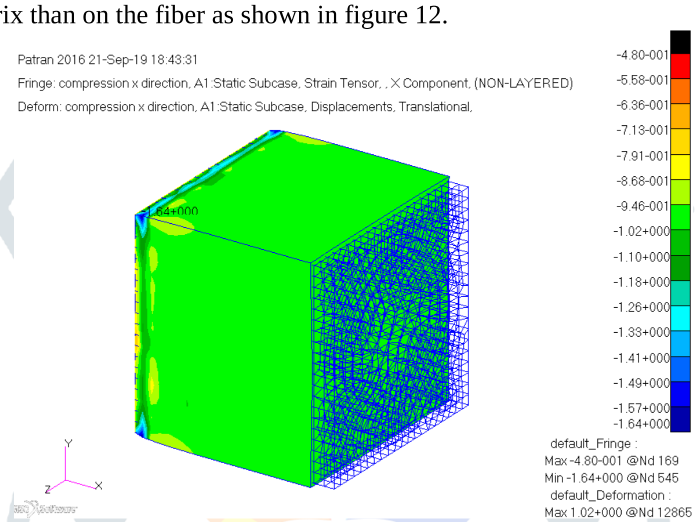

Fig. 13: Strain tensor X-direction (Isometric view)

The strains in the model is as shown in figures 13, the strains are almost uniform through the model except for the matrix at the rear where the model was constrained in all directions. The stresses and strains of each element are recorded from the analysis as shown in Table 4(a).

Table 4: (a) Stress and Strains in Each Element When Displacement is Applied in X Direction

		Stress (GPa)		Strain	
Element	Volume (mm^3)	X	X*Volume	X	X*Volume
350	8.43E-05	-5.915784	-4.98E-04	-0.917549	-7.73E-05
351	0.000104	-5.924603	-6.15E-04	-0.912825	-9.48E-05
352	0.000128	-5.792768	-7.43E-04	-0.893059	-1.14E-04
353	0.000175	-5.655126	-9.91E-04	-0.867726	-1.52E-04
354	0.000163	-5.593449	-9.13E-04	-0.865113	-1.41E-04
355	0.000144	-5.576685	-8.05E-04	-0.863561	-1.25E-04
356	0.000145	-5.447426	-7.92E-04	-0.856754	-1.25E-04
357	0.000177	-5.306689	-9.39E-04	-0.842742	-1.49E-04
358	0.000175	-5.095148	-8.91E-04	-0.830709	-1.45E-04
359	0.000142	-5.063494	-7.20E-04	-0.848037	-1.21E-04
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
7320	0.000154	-475.446503	-7.30E-02	-1.001076	-1.54E-04
7321	0.000255	-475.468018	-1.21E-01	-1.00115	-2.56E-04
7322	0.00023	-475.458191	-1.09E-01	-1.001117	-2.30E-04
7323	7.30E-05	-475.291931	-3.47E-02	-1.000746	-7.31E-05
7324	7.14E-05	-475.079163	-3.39E-02	-1.000292	-7.14E-05
7325	8.05E-05	-475.203949	-3.82E-02	-1.000554	-8.05E-05

7326	0.000215	-475.428223	-1.02E-01	-1.001057	-2.15E-04
7327	0.000147	-475.41864	-6.99E-02	-1.001034	-1.47E-04
7328	0.000133	-475.433167	-6.30E-02	-1.001066	-1.33E-04
7329	0.000109	-475.390686	-5.19E-02	-1.000968	-1.09E-04
∑V	1.00E+00	∑(stress*vol)	-2.65E+02	∑(strain*vol)	-1.00E+00

The data obtained from the analysis is used to calculate the average stress and strains. The Young's modulus is calculated using the average stress and strain as shown in Table 4(b).

$$Average\ Stress = \frac{\sum(\text{stress} * \text{vol})}{\sum \text{V}}$$

$$Average\ Stress = \frac{-2.65\text{E} + 02}{1.00\text{E} + 00}$$

$$Average\ Stress = \mathbf{-2.65E + 02}$$

$$Average\ Streain = \frac{\sum(\text{strain} * \text{vol})}{\sum \text{V}}$$

$$Average\ Streain = \frac{-1.00\text{E} + 00}{1.00\text{E} + 00}$$

$$Average\ Streain = \mathbf{-1.00E + 00}$$

Table 4: (b) Young's Modulus in the Fiber Direction (E_1)

Average Stress in GPa	-265.1935
Average Strain	-1
E_1 (Ex) in GPa	265.1935

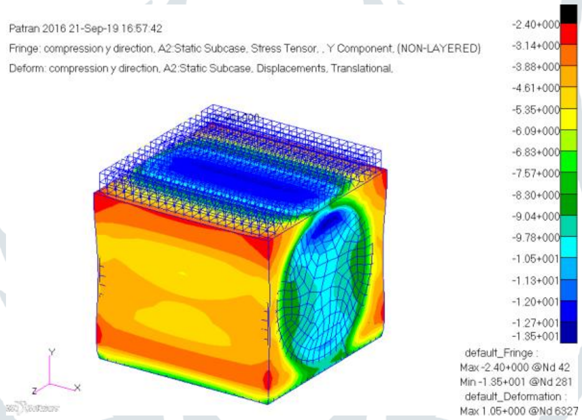

Fig. 14: (a) Stress tensor Y-direction (Isometric view)

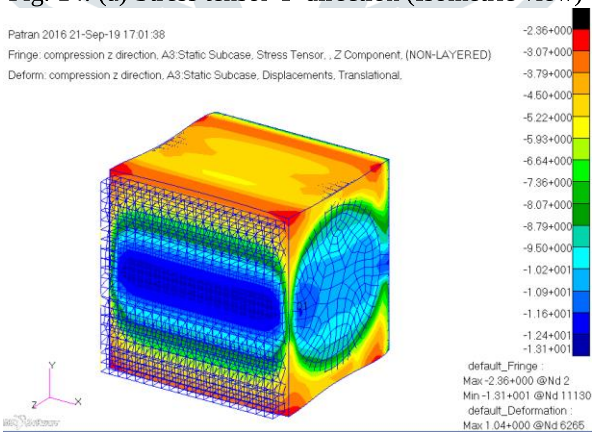

Fig. 14: (b) Stress tensor Z-direction (Isometric view)

The displacement load in the transverse direction is applied in the Y-direction and Z-direction. The stresses can be found through the model in the direction in which the displacement load is applied, the stress is maximum through the matrix on the surfaces and the surface where the load is applied and the fibers experience less stress as shown in Table14 (a) and (b) for Y and Z direction respectively.

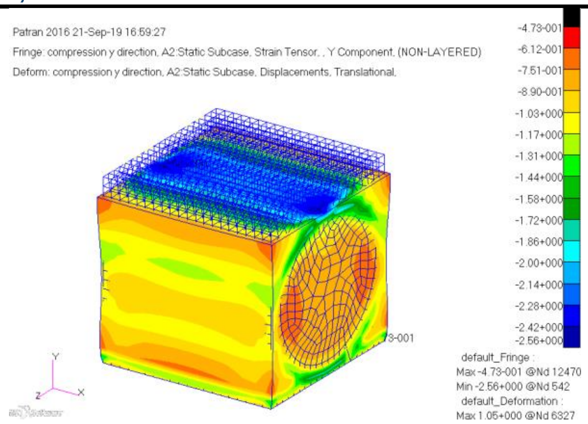

Fig. 15: (a) Strain tensor Y-direction (Isometric view)

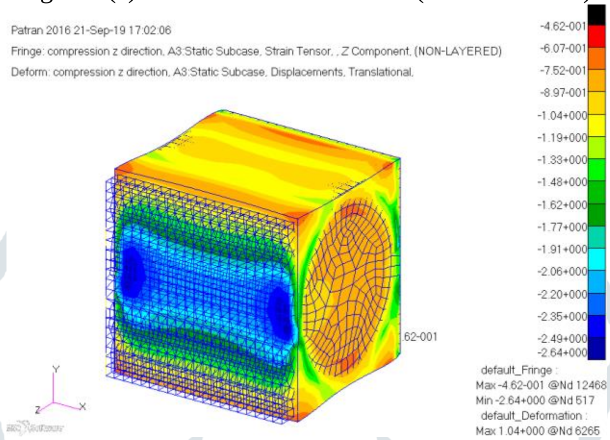

Fig. 15: (b) Strain tensor Z-direction (Isometric view)

It can be seen that from the figure 15(a) and (b), the strains are high throughout the model except for the face that was loaded. The stress and strains acting in each element in Y and Z directions are as shown in Table 5(a) and 5(b) respectively.

Table 5: (a) Stress and Strains in Each Element When Displacement is Applied in Y Direction

		Stress (GPa)		Strain	
Element	Volume(mm^3)	Y	Y*Volume	Y	Y*Volume
350	8.43E-05	-10.586232	-8.92E-04	-1.80297	-1.52E-04
351	0.000104	-10.357267	-1.08E-03	-1.83577	-1.91E-04
352	0.000128	-9.698721	-1.24E-03	-1.83555	-2.35E-04
353	0.000175	-9.000152	-1.58E-03	-1.80911	-3.17E-04
354	0.000163	-8.268178	-1.35E-03	-1.79052	-2.92E-04
355	0.000144	-7.85846	-1.13E-03	-1.75475	-2.53E-04
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
7324	7.14E-05	-11.180834	-7.98E-04	-0.93199	-6.65E-05
7325	8.05E-05	-11.121047	-8.95E-04	-0.92689	-7.46E-05
7326	0.000215	-10.148573	-2.18E-03	-0.8457	-1.82E-04
7327	0.000147	-9.977265	-1.47E-03	-0.83141	-1.22E-04
7328	0.000133	-9.741645	-1.29E-03	-0.81177	-1.08E-04
7329	0.000109	-10.212042	-1.11E-03	-0.85098	-9.29E-05
∑V	1.00E+00	∑(stress*vol)	-8.11E+00	∑(strain*vol)	-1.00E+00

The data obtained from the analysis is used to calculate the average stress and strains.

$$Average\ Stress = \frac{\sum(\text{stress} * \text{vol})}{\sum \text{V}}$$

$$Average\ Stress = \frac{-8.11\text{E} + 00}{1.00\text{E} + 00}$$

$$Average\ Stress = \mathbf{-8.11E + 00}$$

$$Average\ Streain = \frac{\sum(\text{strain} * \text{vol})}{\sum \text{V}}$$

$$Average\ Streain = \frac{-1.00\text{E} + 00}{1.00\text{E} + 00}$$

$$Average\ Streain = \mathbf{-1.00E + 00}$$

Table 5: (b) Stress and Strains in Each Element When Displacement is Applied in Z Direction

		Stress (GPa)		Strain	
Element	Volume (mm^3)	Z	Z*Volume	Z	Z*Volume
350	8.43E-05	-3.81798	-3.22E-04	-0.7785	-6.56E-05
351	0.000104	-4.1102	-4.27E-04	-0.85787	-8.91E-05
352	0.000128	-4.45633	-5.71E-04	-0.96079	-1.23E-04
353	0.000175	-4.82365	-8.46E-04	-1.07935	-1.89E-04
354	0.000163	-5.59108	-9.12E-04	-1.24936	-2.04E-04
355	0.000144	-6.36259	-9.19E-04	-1.4349	-2.07E-04
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
7324	7.14E-05	-8.61194	-6.15E-04	-0.71766	-5.12E-05
7325	8.05E-05	-8.74942	-7.04E-04	-0.72912	-5.87E-05
7326	0.000215	-9.64557	-2.07E-03	-0.8038	-1.73E-04
7327	0.000147	-9.6163	-1.41E-03	-0.80136	-1.18E-04
7328	0.000133	-9.72659	-1.29E-03	-0.81055	-1.07E-04
7329	0.000109	-9.3839	-1.02E-03	-0.78199	-8.54E-05
∑V	1.00E+00	∑(stress*vol)	-8.11E+00	∑(strain*vol)	-1.00E+00

The data obtained from the analysis is used to calculate the average stress and strains. The Young's modulus is calculated using the average stress and strain as shown in Table 5(c).

$$Average\ Stress = \frac{\sum(\text{stress} * \text{vol})}{\sum \text{V}}$$
$$Average\ Stress = \frac{-8.11\text{E} + 00}{1.00\text{E} + 00}$$
$$Average\ Stress = \mathbf{-8.11E + 00}$$

$$Average\ Streain = \frac{\sum(\text{strain} * \text{vol})}{\sum \text{V}}$$
$$Average\ Streain = \frac{-1.00\text{E} + 00}{1.00\text{E} + 00}$$
$$Average\ Streain = \mathbf{-1.00E + 00}$$

Table 6.1.3.4: (c) Young's Modulus in the Transverse Direction (E_2)

	Y-direction	Z-direction
Average Stress in GPa	-8.11307	-8.10878
Average Strain	-0.999974	-0.99989
E_2 in GPa	8.11327	8.109709

4.3 Shear Loading

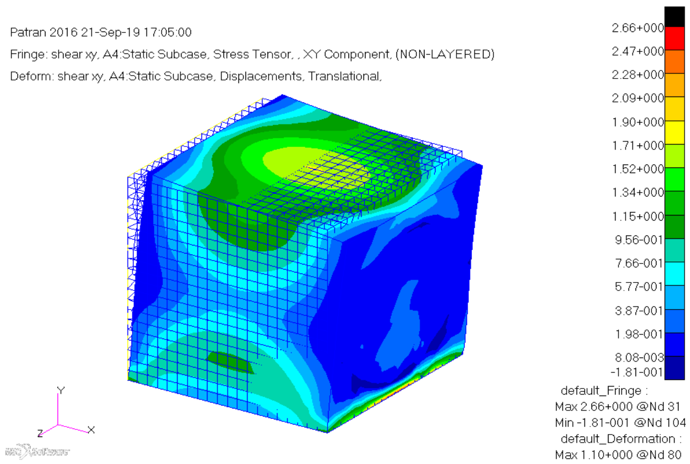

Fig. 16: (a) Stress tensor for shear loading (Isometric view)

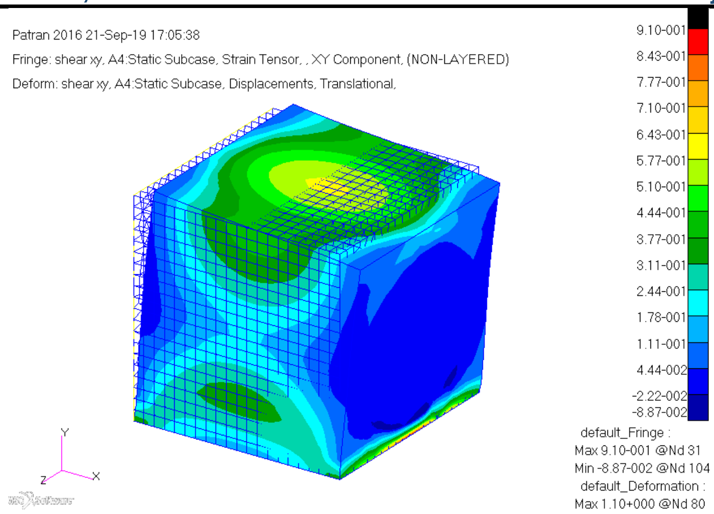

Fig. 16: (b) Strain tensor for shear loading (Isometric view)

The displacement loading for shear is applied in X-direction on the top face of the RVE model, while the face opposite to this is constrained in all directions. Hence, the stresses and strains acting on the model are as shown in figure 16 (a) and (b) respectively. From the figure, it can be seen that there is no change between the stress and strain acting on the model. The stress and strains acting in each element when displacement loading in shear condition is applied are as shown in table 6 (a).

Table 6: (a) Stress and Strains in Each Element When Displacement is Applied in Shear Condition

		Shear Stress(GPa)		Shear Strain	
Element	Volume (mm^3)	XY	XY*Volume	XY	XY*Volume
350	8.43E-05	0.68381	5.76E-05	0.233677	1.97E-05
351	0.000104	0.648212	6.73E-05	0.221513	2.30E-05
352	0.000128	0.580531	7.44E-05	0.198384	2.54E-05
353	0.000175	0.505223	8.86E-05	0.172649	3.03E-05
354	0.000163	0.462826	7.55E-05	0.158161	2.58E-05
355	0.000144	0.431271	6.23E-05	0.147378	2.13E-05
356	0.000145	0.376415	5.47E-05	0.128632	1.87E-05
357	0.000177	0.308028	5.45E-05	0.105262	1.86E-05
358	0.000175	0.221148	3.87E-05	0.075573	1.32E-05
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
7320	0.000154	0.180184	2.77E-05	0.018018	2.77E-06
7321	0.000255	0.213381	5.45E-05	0.021338	5.45E-06
7322	0.00023	0.196313	4.51E-05	0.019631	4.51E-06
7323	7.30E-05	0.158024	1.15E-05	0.015802	1.15E-06
7324	7.14E-05	0.109494	7.81E-06	0.010949	7.81E-07
7325	8.05E-05	0.144345	1.16E-05	0.014434	1.16E-06
7326	0.000215	0.195177	4.19E-05	0.019518	4.19E-06
7327	0.000147	0.182991	2.69E-05	0.018299	2.69E-06
7328	0.000133	0.203796	2.70E-05	0.02038	2.70E-06
7329	0.000109	0.17564	1.92E-05	0.017564	1.92E-06

∑V	1.00E+00	∑(stress*vol)	1.08E+00	∑(stress*vol)	1.98E-01

The data obtained from the analysis is used to calculate the average stress and strains. The Young's modulus is calculated using the average stress and strain as shown in Table 6(b).

$$Average\ Stress = \frac{\sum(\text{stress} * \text{vol})}{\sum V}$$
$$Average\ Stress = \frac{1.08E+00}{1.00E+00}$$
$$Average\ Stress = \mathbf{1.08E+00}$$
$$Average\ Streain = \frac{\sum(\text{strain} * \text{vol})}{\sum V}$$
$$Average\ Streain = \frac{1.98E-01}{1.00E+00}$$
$$Average\ Streain = \mathbf{1.98E-01}$$

Table 6: (b) Shear Modulus (G_{12})

Average Stress in GPa	1.07916
Average Strain	0.19811
G_{12} in GPa	5.447408

The young's modulus and the shear modulus of the RVE model under displacement load are as shown in Table 7.

Table7: Young's modulus and Shear Modulus of the RVE under Displacement Loading

	Tensile Loading	Compression Loading
E_1 (X-direction)	265.1935GPa	265.1935GPa
E_2 (Y-direction)	8.11GPa	8.11 GPa
G_{12} (XY- Shear)	5.447408GPa	

Discussion

This material was only developed in software using the material properties of some constituent materials and hence the analysis results are compared with the theoretical rule of mixture, and the difference is only with the shear modulus of the material. The young's modulus E_1 and E_2 results from analysis are almost the same that was calculated in rule of mixture. Table 8 shows the analytical and theoretical results comparison of the M50J CFRP prepreg system.

Table 8: CFRP Prepreg System Results

	Analysis		Rule of Mixture
	Tensile Loading	Compression Loading	
E_1 (X-direction)	265.1935GPa	265.1935GPa	266.04 GPa
E_2 (Y-direction)	8.11GPa	8.11 GPa	7.87 GPa
G_{12} (XY- Shear)	5.447408GPa		3.05 GPa

V. Acknowledgment

The RVE model of M50J CFRP prepreg system is modelled and analysed in the MSC Patran/Nastran Software.

The modulus of the material is calculated by the rule of mixtures method theoretically, and the results are compared with the analytical results of CFRP prepreg system.

Form both the results, it can be seen that the tensile and compression modulus of the material in analysis is almost the same as that of rule of mixture result and there is a difference in the shear modulus of analysis when compared to the rule of mixture results.

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