EM 4133/6133 Composite Modeling Report

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1. Introduction

My experience in numerical modeling comes from my Vibrations class (EM 3413) where we had to model the behavior of a can of paint releasing a constant quantity of paint every second, attached to a string. Taken into account were the decreasing mass of the can of paint over time and the decreasing length of the string (being elastic).

The paint was released at certain angles relative the x, y, and z axes. We used the equations of motion of a pendulum learned in class and plotted the solutions into MATLAB. We got to use the differential equations solvers embedded in MATLAB such as ODE45. It was a very difficult but rewarding experience because I learned a lot from that.

What I am expecting from this present project is to gain more practical experience in modeling. I created the beam myself and it will be very nice to see the beam behaving the same as in real life. Being able to run the simulation on Abaqus will give me a sense of achievement because I never heard of Abaqus before taking this class. Also this project involves the use of MATLAB. This will help refresh my knowledge in using MATLAB as well.

2. Composite Design

2.1. Prepreg details

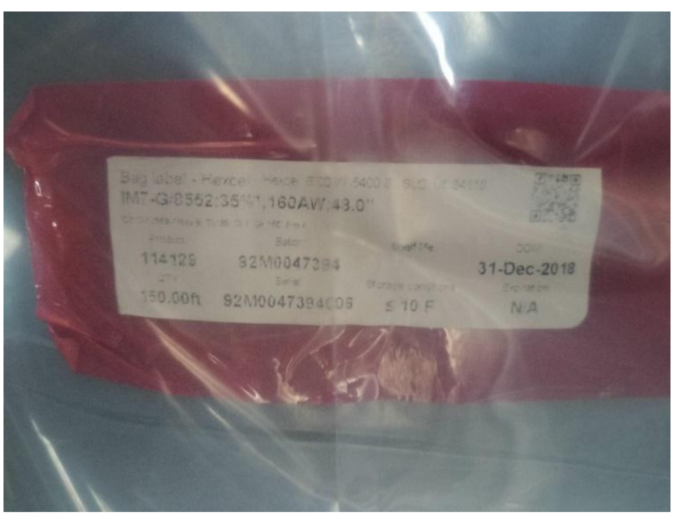


Figure 1: Prepreg card label (Picture by Mr. Cody Hardin)

Figure 2: Picture of the roll (Picture by Hayward Singletary)

The material used for the prepreg was the unidirectional carbon fiber IM7 with the 8552 matrix made of resin. HexPly 8552 is mainly used for primary aircraft structures such as the skin of the fuselage of an aircraft. That material can withstand a large impact. Three different plys with different fiber orientations were produced: plys with 0 deg, 45 deg, and 90 deg. fiber orientation, each with a size of 10.0”x10.0”.
Listed below are different properties of the IM7 8552 composite material with two different orientations” 90 degrees and 0 degree:

Mechanical Properties

Property	Temp°F	Condition	AS4	IM7
0° Tensile strength, ksi	-67	Dry	300	373
0° Tensile modulus, msi	-67	Dry	19.4	23.7
0° Tensile strength, ksi	77	Dry	310	395
0° Tensile modulus, msi	77	Dry	19.6	23.8
0° Tensile elongation, %	77	Dry	1.55	1.62
0° Tensile strength, ksi	195	Dry	293	**368***
0° Tensile modulus, msi	195	Dry	19.1	**23.7***
90° Tensile strength, ksi	-67	Dry	9.73	9.60
90° Tensile modulus, msi	-67	Dry	1.50	1.46
90° Tensile strength, ksi	77	Dry	9.27	9.3
90° Tensile modulus, msi	77	Dry	1.39	1.70
90° Tensile strength, ksi	200	Dry	-	-
90° Tensile modulus, msi	200	Dry	1.22	1.50
Major Poisson's Ratio, tension	77	Dry	0.302	0.316
± 45 Inplane shear	77	Dry	16.6	17.4
± 45 Inplane shear	200	Dry	15.2	**15.4***
Major Poisson's Ratio, compression	77	Dry	0.335	0.356
0° Compression strength, ksi	-67	Dry	253	292
0° Compression modulus, msi	-67	Dry	18	20.5
0° Compression strength, ksi	77	Dry	222	245
0° Compression modulus, msi	77	Dry	18.6	21.7
0° Compression strength, ksi	195	Dry	184	215
0° Compression modulus, msi	195	Dry	17.7	23.5
0° Compression strength, ksi	160	Wet	203	-
0° Compression modulus, msi	160	Wet	17.0	-
0° Compression strength, ksi	195	Wet	184	**173♥**
0° Compression modulus, msi	195	Wet	18.1	**20.7♥**
Fill compression strength, ksi	-67	Dry	51.4	55.3
Fill compression modulus, msi	-67	Dry	1.56	1.53
Fill compression strength, ksi	77	Dry	38.9	44.2
Fill compression modulus, msi	77	Dry	1.43	1.82
Fill compression strength, ksi	195	Dry	-	-
Fill compression modulus, msi	195	Dry	-	-
Fill compression strength, ksi	77	Wet	-	34.2
Fill compression strength, ksi	160	Wet	-	**24.6****
Fill compression strength, ksi	195	Wet	**19.7♥**	**19♥**
Compression after impact, ksi				
after 500 in-in-lb/in impact	77	Dry	50	-
after 1,500 in-in-lb/in impact	77	Dry	32	34
after 2,000 in-in-lb/in impact	77	Dry	28	-
after 2,500 in-in-lb/in impact	77	Dry	27	-

Bold - 200° **Bold*** - 220° **Bold**** - 180° **Bold ♥** - 250°

Property	Temp°F	Condition	AS4	IM7
0° Short beam shear, ksi	-67	Dry	23.8	21
0° Short beam shear, ksi	77	Dry	18.5	19.9
0° Short beam shear, ksi	195	Dry	**14.7♥**	**13.6***
0° Short beam shear, ksi	77	Wet	16.9	16.7
0° Short beam shear, ksi	160	Wet	12.2	**11.6****
0° Short beam shear, ksi	195	Wet	**8.25♥**	**8.25♥**
Fill short beam shear, ksi	-67	Dry	-	-
Fill short beam shear, ksi	77	Dry	-	-
Fill short beam shear, ksi	195	Dry	-	-
Fill short beam shear, ksi	77	Wet	-	-
Fill short beam shear, ksi	195	Wet	-	-
0° Flexural strength, ksi	77	Dry	274	270
0° Flexural modulus, msi	77	Dry	18.4	22
Quasi-Isotropic 25/50/25				
Tensile strength, ksi	77	Dry	107	104
OHT strength, ksi	77	Dry	63.5	62.1
OHC strength, ksi	77	Dry	47.8	48.9
CAI strength, ksi	77	Dry	34.6	31
CBI strength, ksi	77	Dry	91.2	-

Bold - 200° **Bold*** - 220° **Bold**** - 180° **Bold ♥** - 250°

Figure 3: Table showing the different properties of the prepreg (from www.hexcel.com)

2.2. Laminate design

My fiber orientations are the following:
[0/90/±45/±45/90/0]
The details of my layup can be found in figure 4. Each prepreg has a thickness of 0.131 mm. Therefore, the total thickness of my plate is 1.048 mm.

The dimensions are in mm.

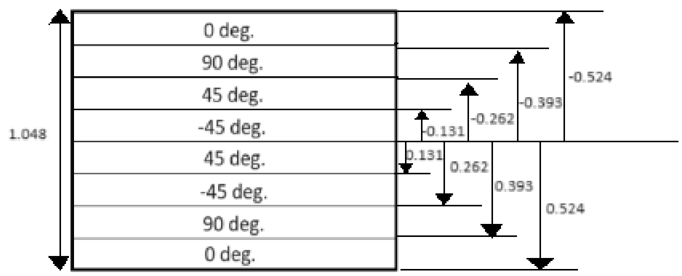


Figure 4: My fiber orientations (Onitiana Razafimino)

3. Experimental work

3.1. Tensile test

3.1.1. Experimental Setup

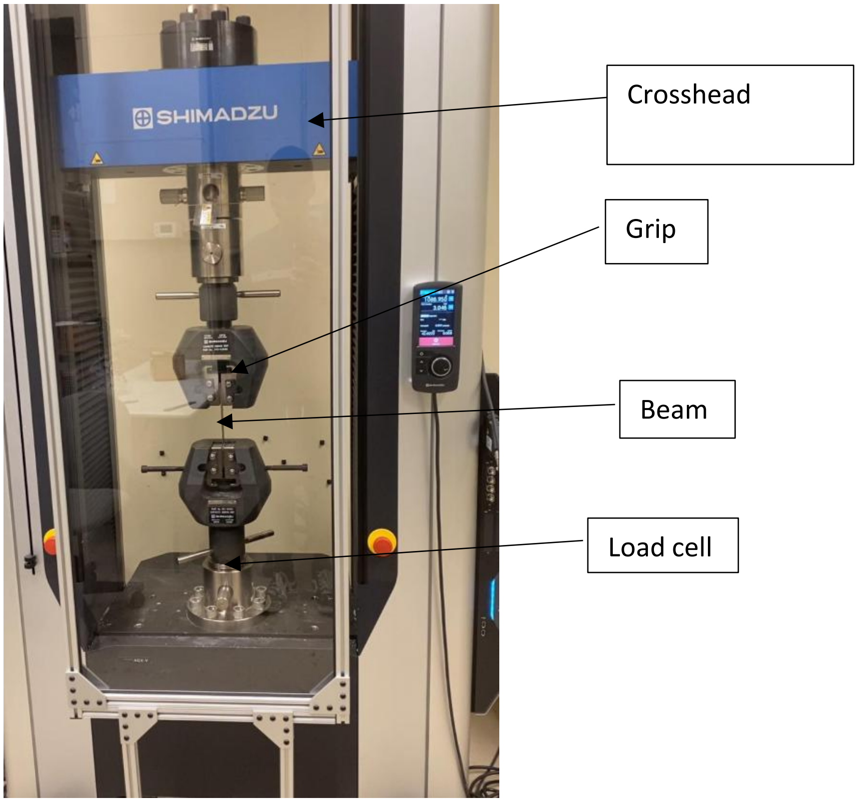


Figure 5. Experimental setup for the tension test done on March 19th at 1:10pm (Onitiana Razafimino)

The purpose of this task is to first evaluate how much tension the beam that I manufactured can withstand longitudinally. I will be able to visualize how stress and strain behave as tension increases.

3.1.2. Experimental results

Maximum load (lb)	Displacement (in)	Strain (%)	Stress (psi)
4318.689	0.093843	1.173035	79975.73

Figure 6. Data table for specimen 1

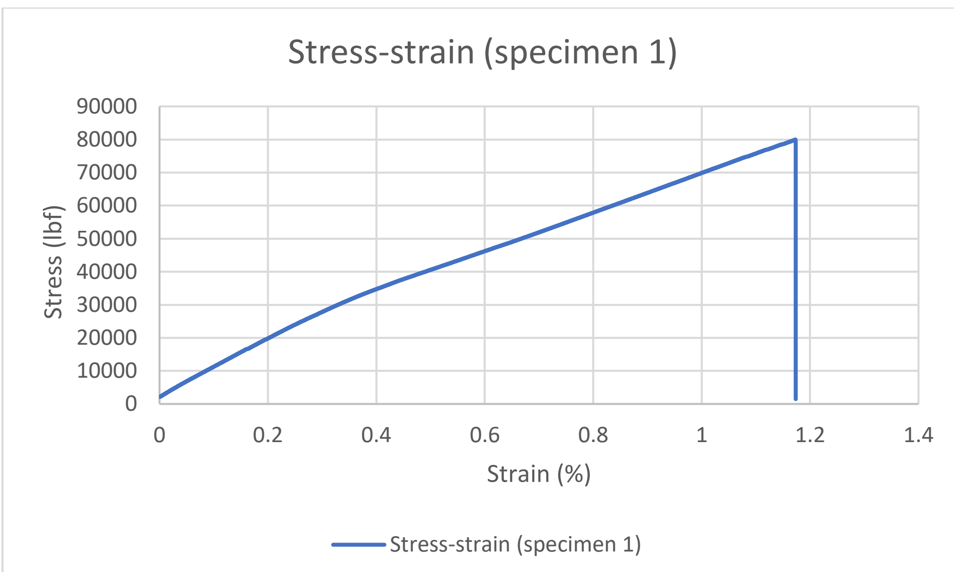


Figure 7. Load-displacement and Stress-strain graphs for specimen 1

Specimen 2

3.2. Bending test

3.2.1. Experimental Setup

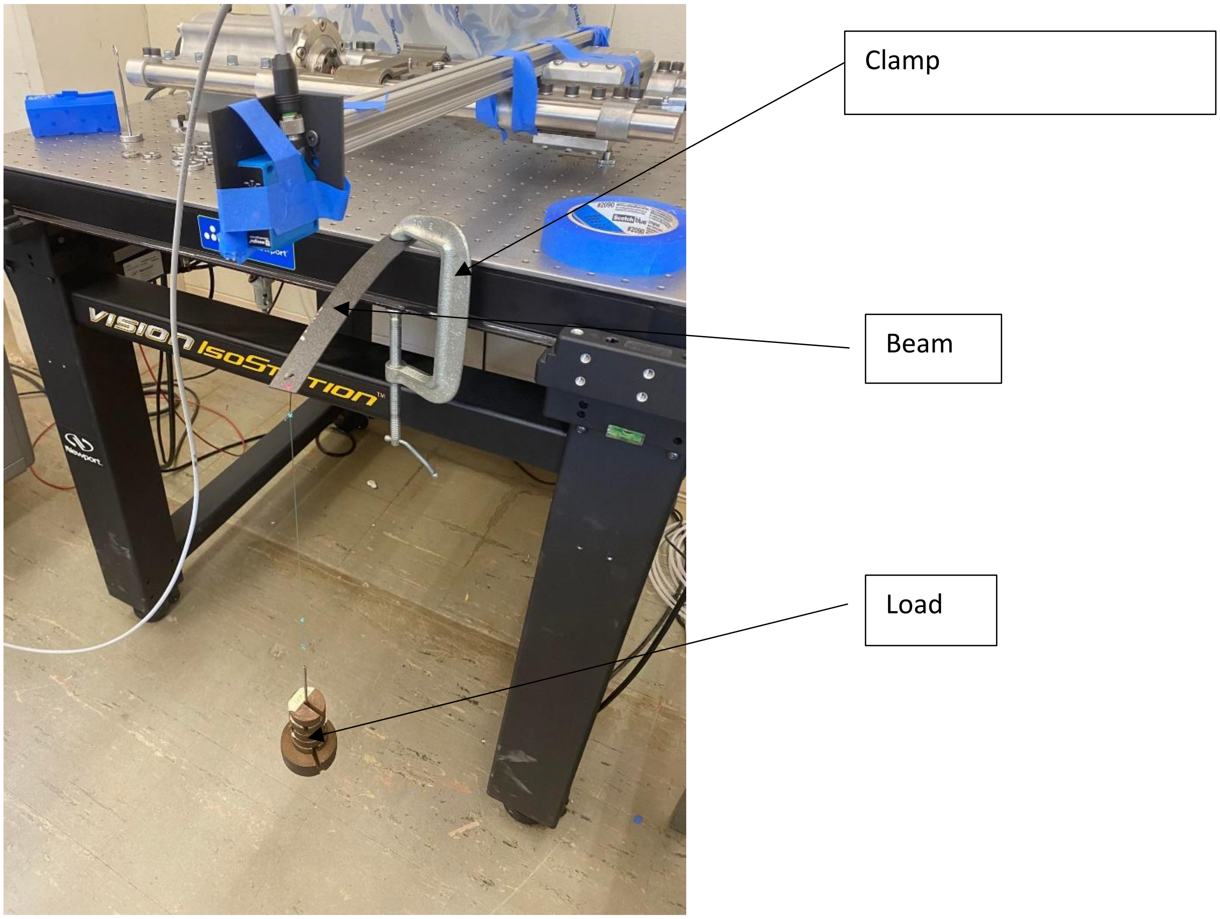


Figure 8. Experimental setup for the tension test done on April 24th at 2:15pm (Onitiana Razafimino)

The goal of this task is to primarily evaluate how much load the beam that I manufactured can withstand vertically.

3.2.2. Experimental results

Mass (g)	Force (N)	Displacement (mm)
0	0	47.8
36.3	0.356103	49.34
56.3	0.552303	50.3
76.3	0.748503	51.26
96.3	0.944703	52.26
116.3	1.140903	53.2
136.3	1.337103	54.32
156.3	1.533303	55.31
176.3	1.729503	56.3
196.3	1.925703	57.48
216.3	2.121903	58.59

236.3	2.318103	59.32
311.3	3.053853	62.54
578.5	5.675085	74.98
692.3	6.791463	80.23
793.05	7.7798205	84.53
902.78	8.8562718	89.19
1010.75	9.9154575	94.35
1118.65	10.9739565	98.87

Figure 9. Force and displacement data

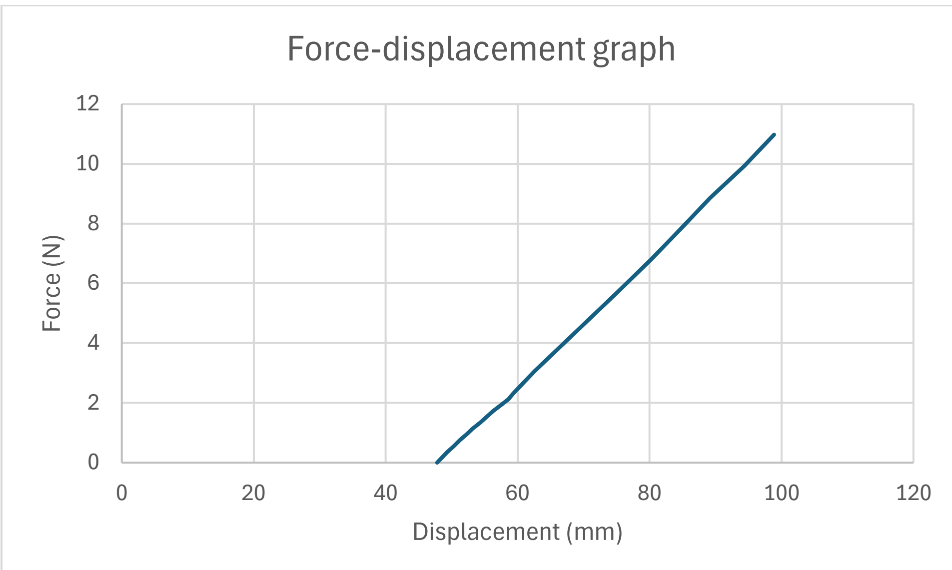


Figure 10. Force-displacement graph

4. Analytical work

4.1. Lamina analysis

I started by finding the generalized Q bar matrices using the following formulas:

$Q_{11} = \frac{E1}{1-v12*v21}$

$Q_{12} = Q_{21} = \frac{v12*E2}{1-v12*v21}$

$Q_{22} = \frac{E2}{1-v12*v21}$

$Q_{33} = G12$

$Q_{13} = Q_{23} = Q_{31} = Q_{32} = 0$

Using the following information: E1 = 22.99 Msi, E2 = 1.30 Msi, v12 = 0.316, v21 = 0.024, G12 = 0.68 Msi, we can build the Q Matrix.

Q bar matrix for 0 degree lamina:

$$\begin{matrix} 23.1657 & 0.413939 & 0 \\ 0.413939 & 1.30993 & 0 \\ 0 & 0 & 0.68 \end{matrix} \quad [\text{Msi}]$$

By using mathematica workbook, I got the following results:

Q bar matrix for 45 degree lamina:

$$\begin{matrix} 11.7898 & 11.7898 & 22.7517 \\ 0.861937 & 0.861937 & -0.895995 \\ -0.34 & 0.34 & 0 \end{matrix} \quad [Msi]$$

Q bar matrix for -45 degrees lamina:

$$\begin{matrix} 11.7898 & 11.7898 & -22.7517 \\ 0.861937 & 0.86937 & 0.895995 \\ 0.34 & -0.34 & 0 \end{matrix} \; [Msi]$$

Q bar matrix for 90 degrees lamina:

$$\begin{matrix} 0.413939 & 23.1657 & 0 \\ 1.30993 & 0.413939 & 0 \\ 0 & 0 & -0.68 \end{matrix} \quad [Msi]$$

4.2. Lamiante analysis

We have the following matrix as A'B'D' matrix:

$$\begin{matrix} 19.8758 & -250.072 & 0.000 & 0.000 & 0.000 & 16370.6 \\ -19.3259 & 264.035 & 0.000 & 0.000 & 0.000 & -16370.6 \\ 0.000 & 0.000 & 994.513 & -133.165 & 2742.46 & 0.000 \\ 0.000 & 0.000 & 16370.6 & 765.175 & 19429.8 & 0.000 \\ 0.000 & 0.000 & -16370.6 & -10.8661 & -275.92 & 0.000 \\ -156.738 & 2143.9 & 0.000 & 0.000 & 0.000 & 0.000 \end{matrix} \quad 1/\text{Msi}$$

The effective extensional modulus is given by the following formula:

$E_x^{ex}=\frac{1}{hA'11} = \frac{1}{0.054\ in*19.8758\ 1/(Msi*in)} = 0.9317\ Msi$ = 6.433 GPa

The effective flexural modulus is given by the following formula:

$E_x^{fl} = \frac{1}{h^3*D'11} = \frac{1}{(0.054\ in)^3*765.175\ 1/(Msi*in)} = 8.2996\ Msi = 57.22\ GPa$

4.3. Tension test analysis

Strain is given by the following formula:

$\varepsilon_x = P/(AE_x^{ex})$, therefore: ε_x = 4318.389 lbs / (0.054 in * 1 in * 0.9317 Msi)

$\varepsilon_x = 0.08582$

Because the effective length of the beam is 4 inches the displacement is given by the following formula:

$\Delta L = \varepsilon_x * 4 \text{ in} = 0.08583 * 4 \text{ in}$

$\Delta L = 0.3433 \text{ in}$

The strain value is also given by the formula:

$\varepsilon_x = \sigma_x/E_x^{ex}$ = 79975.73E-6 Msi / 0.9317 Msi = 0.08584

$\varepsilon_x = 0.08584$

	Calculated value	Experimental value	% error
Displacement	0.3433	0.093843	-72%
Strain	0.08584	0.01173	-86%

$\sigma_x = E_x^{ex} * \varepsilon_x$ = 0.9317 Msi * 0.01173 = 10929 psi

	Calculated value	Experimental value	% error
Stress	10929	79975.73	

Maximum stress criteria

Maximum stress = 79975.73 psi

Maximum force = 4318.389 lbs

To avoid failure, stress must be between -4318.389 psi and 4318.389 psi. Since 79975.73 >> 4318.389 psi, the material will fail.

4.4. Bending test analysis

Load (N)	Displacement(m)
0	0.0478
0.356103	0.04934
0.552303	0.0503

0.748503	0.05126
0.944703	0.05226
1.140903	0.0532
1.337103	0.05432
1.533303	0.05531
1.729503	0.0563
1.925703	0.05748
2.121903	0.05859
2.318103	0.05932
3.053853	0.06254
5.675085	0.07498
6.791463	0.08023
7.779821	0.08453
8.856272	0.08919
9.915458	0.09435
10.97396	0.09887

5. Numerical work

5.1. Theoretical background

- 3D Deformable Shell Planar S8R5

S8R5 is a three-dimensional shell element with 8 nodes with a conventional stress/displacement with reduced integration and 5 degrees of freedom (Abaqus Manual).

- 3D Deformable Solid Extrusion C3D8I

C3D8I is an 8-node linear brick with incompatible mode. In short, incompatible mode eliminates the parasitic shear stresses due to bending load. Linear variation of stress perpendicular to the bending direction occurs, but incompatible mode helps prevent this, which leads to more accurate results (Abaqus Manual)

5.2. Specimen modeling

The shell model has 64 elements, 16 elements along the x-axis, 4 elements along the y-axis.

The solid model has 512 total elements, 16 elements along the x-axis, 4 elements along the y-axis, and a total number of nodes of 765.

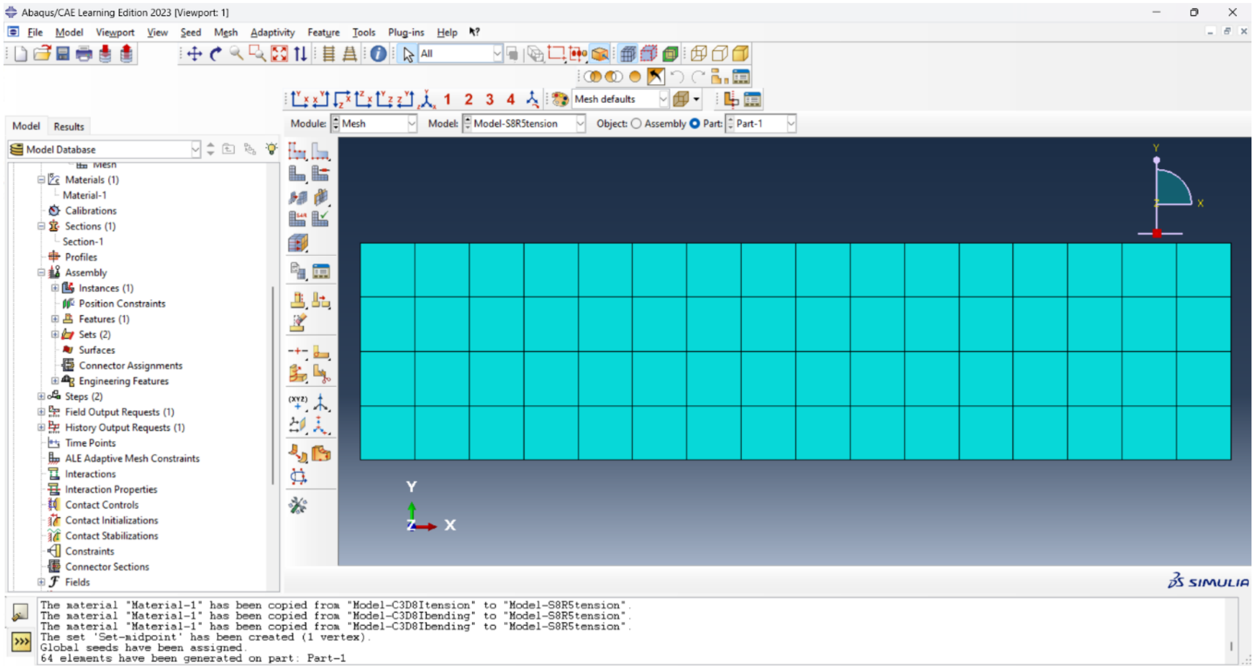


Figure 11. Mesh in the x-y plane for Shell (Onitiana Razafimino)

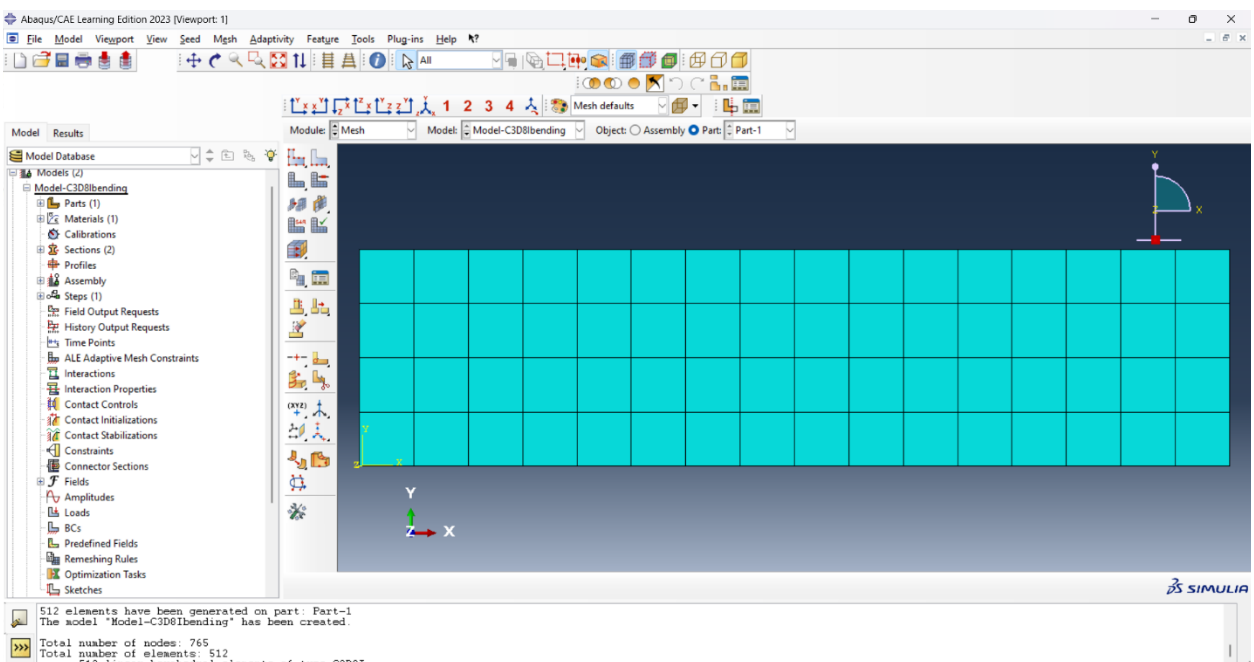


Figure 12. Mesh in the x-y plane for Solid (Onitiana Razafimino)

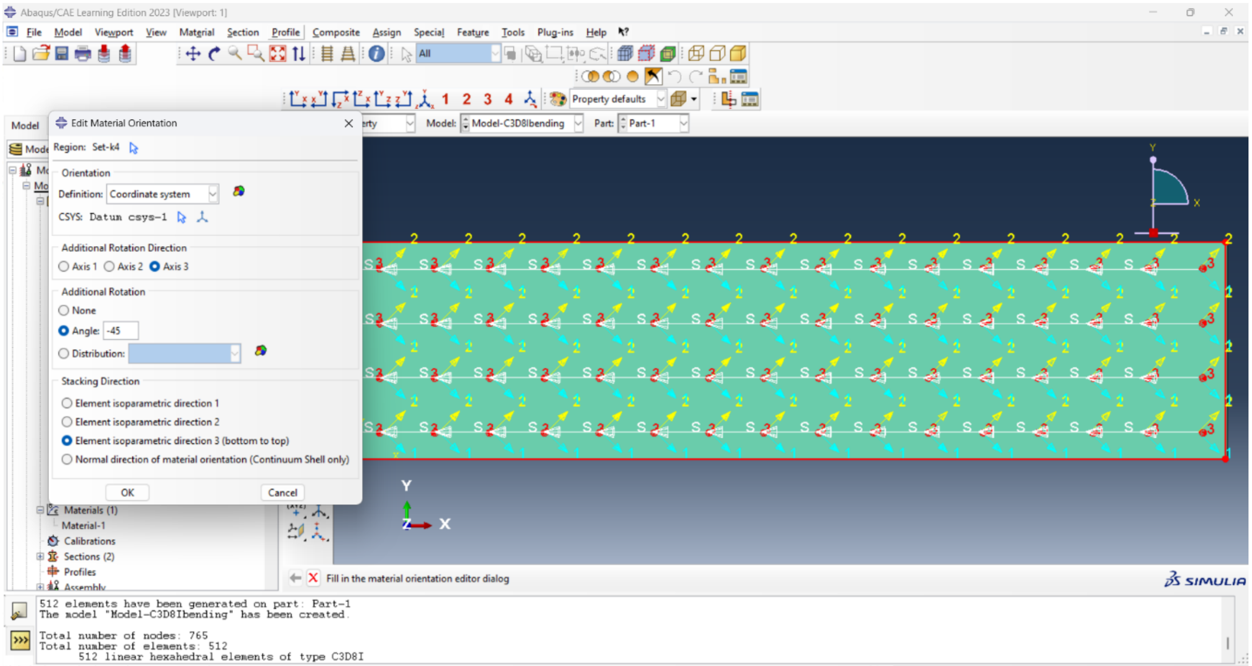


Figure 13. Section detail for the Shell case (Onitiana Razafimino)

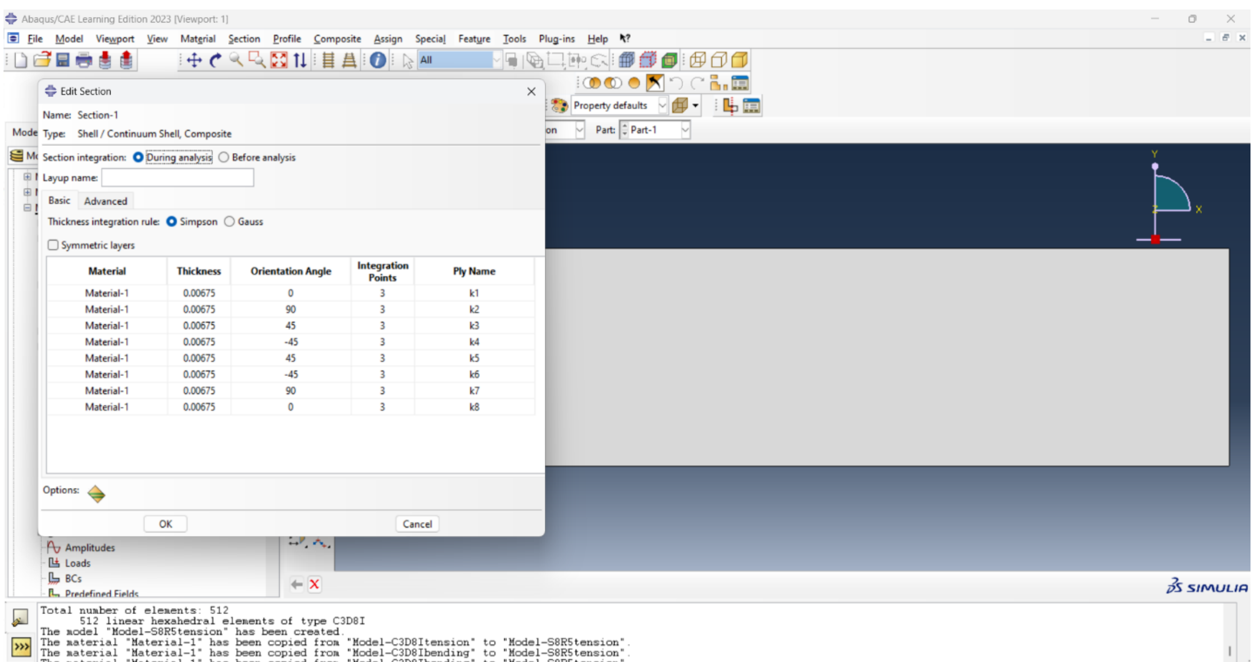


Figure 14. Material orientations for the Solid case (Onitiana Razafimino)

5.3. Model validation

Simulation on the beam is conducted to see if the results we obtained experimentally are valid. Model can also help us visualize the behavoir of the beam over time.

5.3.2. Tension test

S8R5	
Strain (%)	Stress (psi)
0.07029	16310.8
0.140579	32621.7
0.210869	48932.5
0.281158	65243.4
0.351448	81554.2

C3D8I	
Strain (%)	Stress (psi)
0	0
0.0359	8306.36
0.071799	16612.7
0.107699	24919.1
0.143599	33225.4
0.179499	41531.8
0.215398	49838.1
0.251298	58144.5
0.287198	66450.8
0.323097	74757.2

Analytical	
Strain (%)	Stress (psi)
0	0
0.0854	10929
0.54	70000

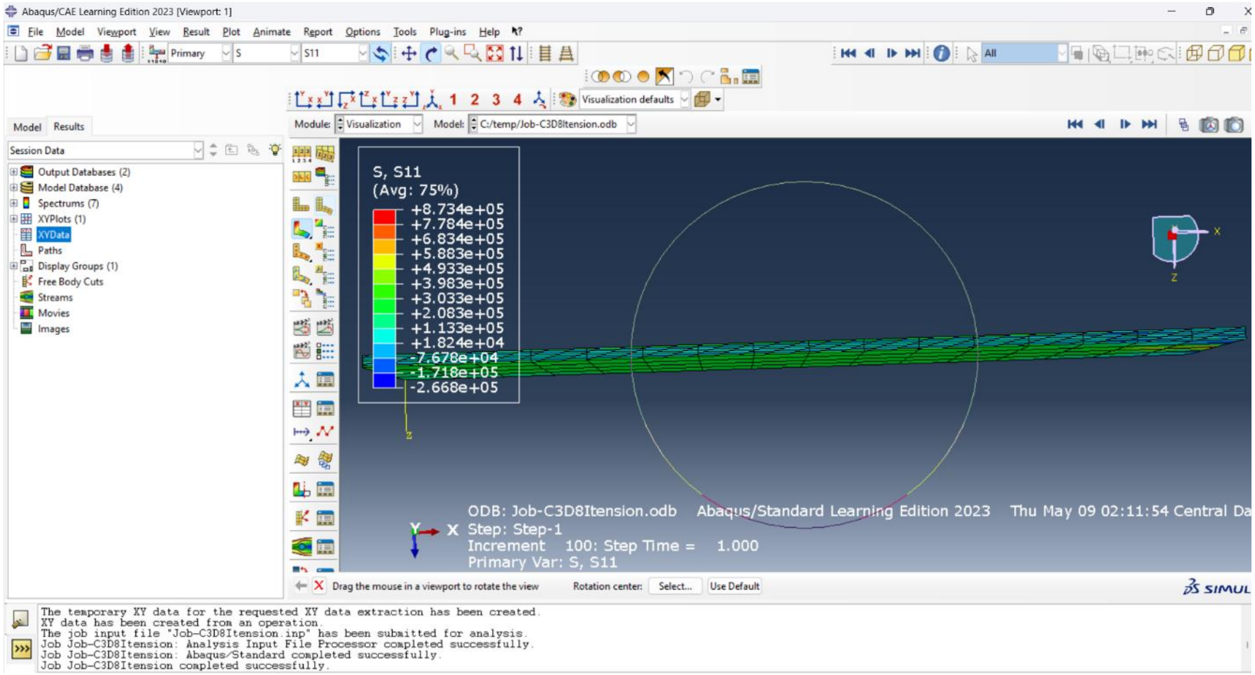


Figure 15. Screenshot of the deformed shape of the C3D8I model (Onitiana Razafimino)

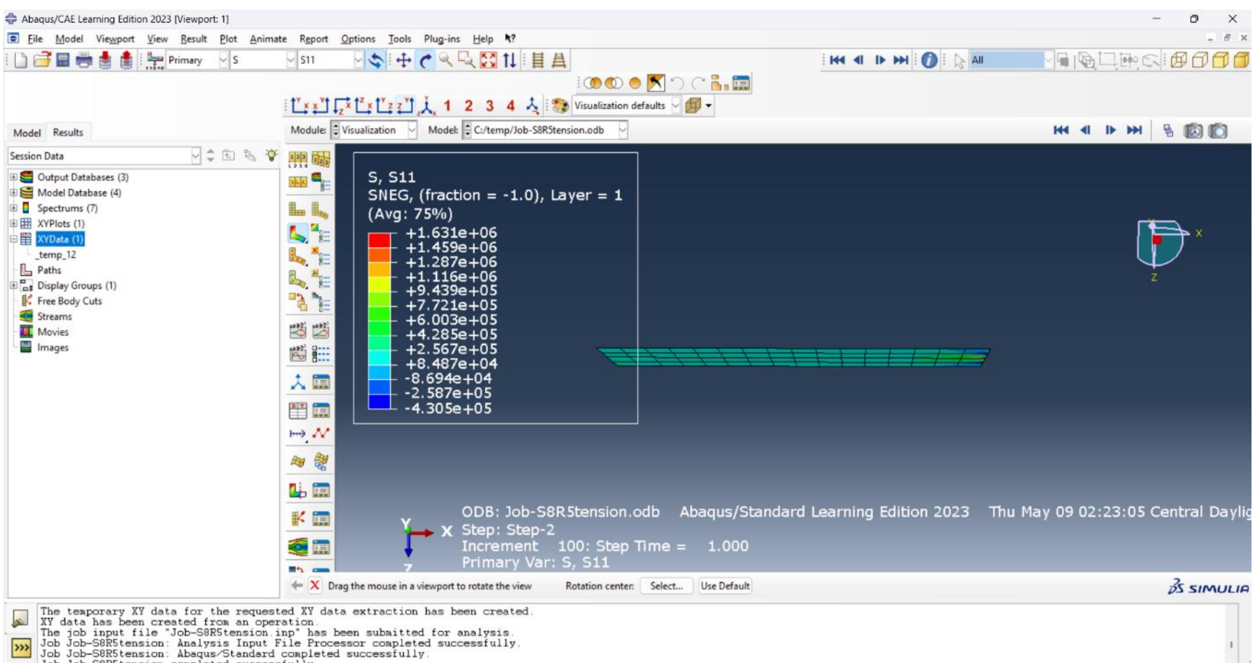


Figure 16. Screenshot of the deformed shape of the S8R5 model (Onitiana Razafimino)

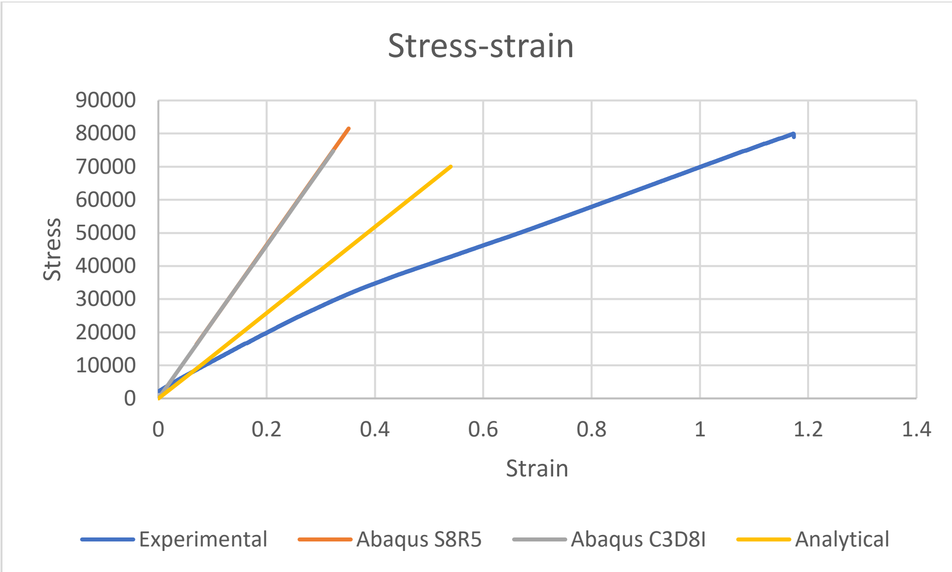


Figure 17. Stress-strain curves of experimental, S8R5, C3D8I, Analytical solutions (Onitiana Razafimino)

The two different models are very closely related, while the analytical solution is a little off, but closer to the experimental results.

5.3.3. Bending test

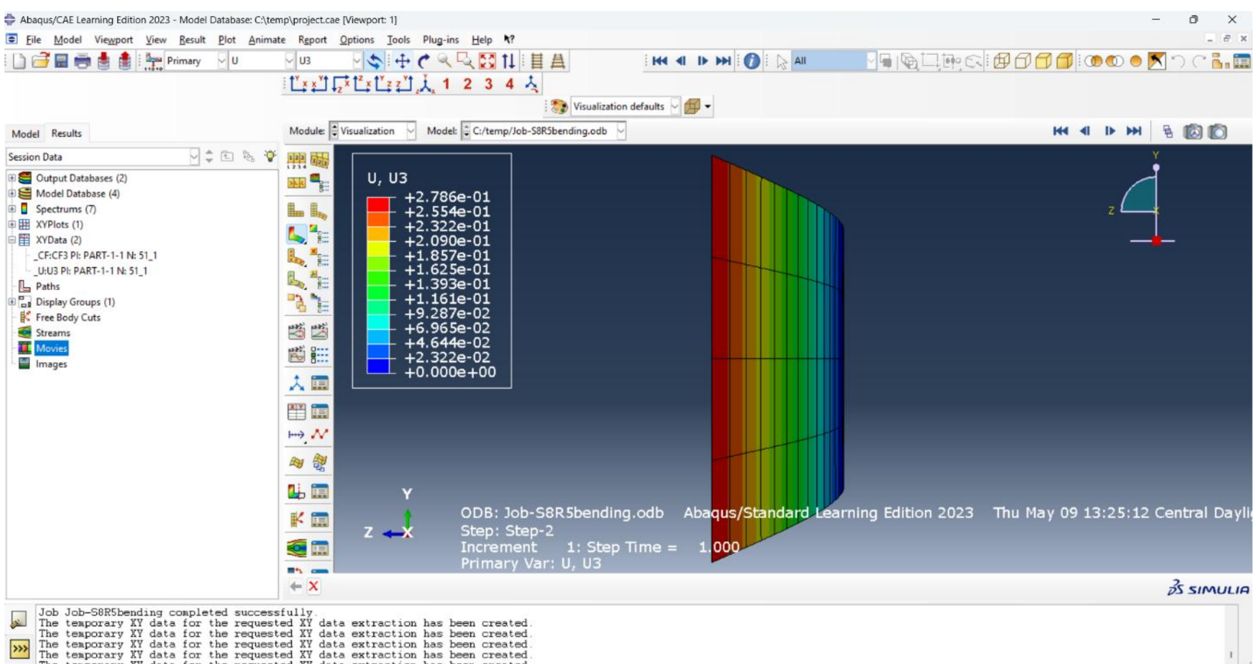


Figure 18. Screenshot of the deformed shape of the S8R5 model (Onitiana Razafimino)

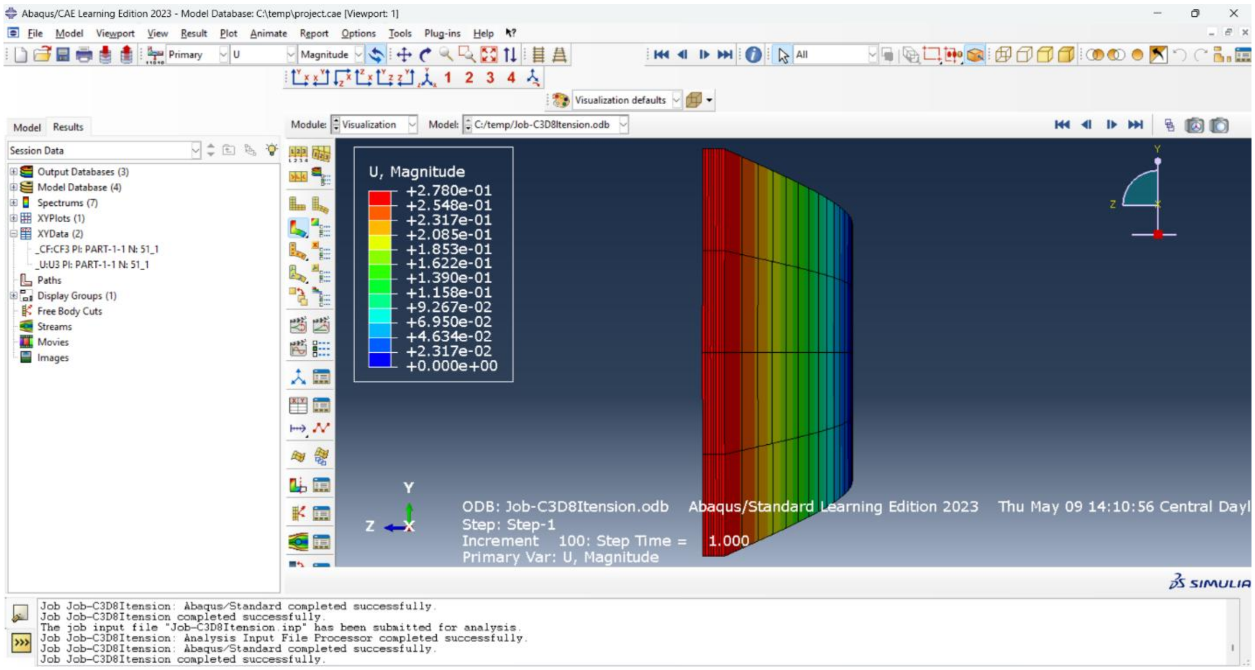
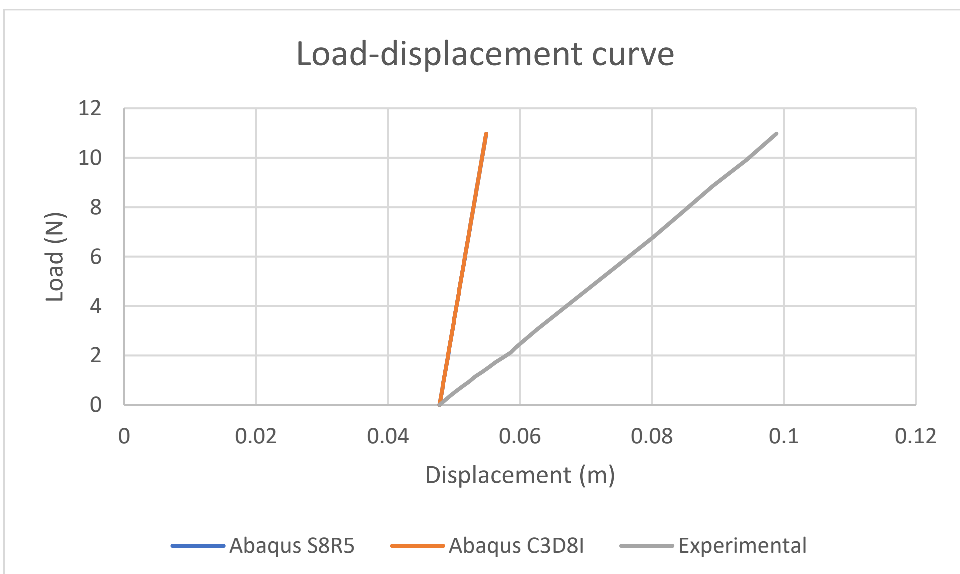


Figure 19. Screenshot of the deformed shape of the C3R8I model (Onitiana Razafimino)



The results of Abaqus C3DI8 oscillates, but are very similar to the other model S8R5

6. Discussion

Modeling is definitely easier than the analysis. The most rewarding part is when the analytical and experimental solutions previously predicted are validated by the model, but this requires a mastery of the Abaqus software. My modeling is unfinished, and I am missing some parts. However, I got some results and the beam general behavior under tension match the experimental behaviors under tension. Running a numerical simulation with quadratic seeds provides more accurate results than running a simulation with linear seeds. Different element types on Abaqus have different number of nodes and seeds and provide different levels of accuracy. In our example, the solid element C3D8I provides more accurate results, but depending on the simplicity of the material tested, we could choose a shell model to avoid unnecessary correction on the model.

This project sparked my interest in Abaqus. Through the modeling, I was just following the Abaqus tutorial given in class. There are some commands that I did not understand the use and that I just followed, but I know that each command has a meaning. The more you know about the software, the more powerful it becomes.

I have just been introduced to Finite Element Analysis in my Structural Analysis 2 class and it is fascinating how accurate the results are. I am willing to go more in depth into that field will learn more about Abaqus during the summer, and this will help me a lot in my Senior Design project.

Reference

Abaqus manual

Appendix A. Calculation of Q-bar matrices

```
E1 = 22.99
E2 = 1.30
v12 = 0.316
v21 = 0.024
G12 = 0.68
thetazero = 0
theta1 = Pi / 4
theta2 = -Pi / 4
theta3 = Pi / 2
```

0 degree

$$\text{Qbar0} = \begin{pmatrix} \text{E1 / (1 - v12 * v21)} & \text{(v12 * E2) / (1 - v12 * v21)} & 0 \\ \text{(v12 * E2) / (1 - v12 * v21)} & \text{E2 / (1 - v12 * v21)} & 0 \\ 0 & 0 & \text{G12} \end{pmatrix} . \begin{pmatrix} \text{Cos[thetazero]^2} & \text{Sin[thetazero]^2} & \text{2 * Cos[thetazero] * Sin[thetazero]} \\ \text{Sin[thetazero]^2} & \text{Cos[thetazero]^2} & \text{-2 * Cos[thetazero] * Sin[thetazero]} \\ \text{-Cos[thetazero] * Sin[thetazero]} & \text{Cos[thetazero] * Sin[thetazero]} & \text{Cos[thetazero]^2 - Sin[thetazero]^2} \end{pmatrix}$$

45 degrees

Qbar45

$$\text{Qbar45} = \begin{pmatrix} \text{E1 / (1 - v12 * v21)} & \text{(v12 * E2) / (1 - v12 * v21)} & 0 \\ \text{(v12 * E2) / (1 - v12 * v21)} & \text{E2 / (1 - v12 * v21)} & 0 \\ 0 & 0 & \text{G12} \end{pmatrix} . \begin{pmatrix} \text{Cos[theta1]^2} & \text{Sin[theta1]^2} & \text{2 * Cos[theta1] * Sin[theta1]} \\ \text{Sin[theta1]^2} & \text{Cos[theta1]^2} & \text{-2 * Cos[theta1] * Sin[theta1]} \\ \text{-Cos[theta1] * Sin[theta1]} & \text{Cos[theta1] * Sin[theta1]} & \text{Cos[theta1]^2 - Sin[theta1]^2} \end{pmatrix}$$

-45 degrees

Qbarn45

$$\text{Qbarn45} = \begin{pmatrix} \text{E1 / (1 - v12 * v21)} & \text{(v12 * E2) / (1 - v12 * v21)} & 0 \\ \text{(v12 * E2) / (1 - v12 * v21)} & \text{E2 / (1 - v12 * v21)} & 0 \\ 0 & 0 & \text{G12} \end{pmatrix} . \begin{pmatrix} \text{Cos[theta2]^2} & \text{Sin[theta2]^2} & \text{2 * Cos[theta2] * Sin[theta2]} \\ \text{Sin[theta2]^2} & \text{Cos[theta2]^2} & \text{-2 * Cos[theta2] * Sin[theta2]} \\ \text{-Cos[theta2] * Sin[theta2]} & \text{Cos[theta2] * Sin[theta2]} & \text{Cos[theta2]^2 - Sin[theta2]^2} \end{pmatrix}$$

90 degrees

$$\text{Qbar90} = \begin{pmatrix} \text{E1 / (1 - v12 * v21)} & \text{(v12 * E2) / (1 - v12 * v21)} & 0 \\ \text{(v12 * E2) / (1 - v12 * v21)} & \text{E2 / (1 - v12 * v21)} & 0 \\ 0 & 0 & \text{G12} \end{pmatrix} . \begin{pmatrix} \text{Cos[theta3]^2} & \text{Sin[theta3]^2} & \text{2 * Cos[theta3] * Sin[theta3]} \\ \text{Sin[theta3]^2} & \text{Cos[theta3]^2} & \text{-2 * Cos[theta3] * Sin[theta3]} \\ \text{-Cos[theta3] * Sin[theta3]} & \text{Cos[theta3] * Sin[theta3]} & \text{Cos[theta3]^2 - Sin[theta3]^2} \end{pmatrix}$$

```
In[156]:= Qbar0
          Qbar45
          Qbarn45
          Qbar90

Out[156]=
          {{23.1657, 0.413939, 0.}, {0.413939, 1.30993, 0.}, {0., 0., 0.68}}

Out[157]=
          {{11.7898, 11.7898, 22.7517}, {0.861937, 0.861937, -0.895995}, {-0.34, 0.34, 0.}}

Out[158]=
          {{11.7898, 11.7898, -22.7517}, {0.861937, 0.861937, 0.895995}, {0.34, -0.34, 0.}}

Out[159]=
          {{0.413939, 23.1657, 0.}, {1.30993, 0.413939, 0.}, {0., 0., -0.68}}
```

Appendix B. Calculation of the inverted D matrix (D')

	Qbar11	Qbar12	Qbar21	Qbar22	Qbar16	Qbar 26	Qbar 31	Qbar 32	Qbar 36
0	23.1657	0.413939	0.413939	1.30993	0	0	0	0	0.68
90	0.41394	23.1657	1.30993	0.413939	0	0	0	0	-0.68
45	11.7898	11.7898	0.861937	0.861937	22.7517	-0.895995	-0.34	0.34	0
-45	11.7898	11.7898	0.861937	0.861937	-22.7517	0.895995	0.34	-0.34	0
45	11.7898	11.7898	0.861937	0.861937	22.7517	-0.895995	-0.34	0.34	0
-45	11.7898	11.7898	0.861937	0.861937	-22.7517	0.895995	0.34	-0.34	0
90	0.41394	23.1657	1.30993	0.413939	0	0	0	0	-0.68
0	23.1657	0.413939	0.413939	1.30993	0	0	0	0	0.68

tiffness matrix

rientatio	Thicknes	A11	A12	A21	A22	A16	A26	A31	A32	A36
0	0.00675	0.15636848	0.00279409	0.00279409	0.00884203	0	0	0	0	0.00459
90	0.00675	0.00279409	0.15636848	0.00884203	0.00279409	0	0	0	0	-0.00459
45	0.00675	0.07958115	0.07958115	0.00581807	0.00581807	0.15357398	-0.00604797	-0.002295	0.002295	0
-45	0.00675	0.07958115	0.07958115	0.00581807	0.00581807	-0.15357398	0.00604797	0.002295	-0.002295	0
45	0.00675	0.07958115	0.07958115	0.00581807	0.00581807	0.15357398	-0.00604797	-0.002295	0.002295	0
-45	0.00675	0.07958115	0.07958115	0.00581807	0.00581807	-0.15357398	0.00604797	0.002295	-0.002295	0
90	0.00675	0.00279409	0.15636848	0.00884203	0.00279409	0	0	0	0	-0.00459
0	0.00675	0.15636848	0.00279409	0.00279409	0.00884203	0	0	0	0	0.00459

	0.63665	**0.63665**	**0**
A=	**0.046545**	**0.046545**	**0**
	0	**0**	**0**

matrix

z	B11	N12	B21	B22	B16	B26	B31	B32	B36
-0.027	-0.00738841	-0.00013202	-0.00013202	-0.00041779	0	0	0	0	-0.00021688
-0.0203	-9.43E-05	-0.00527744	-0.00029842	-9.43E-05	0	0	0	0	0.00015491
-0.0135	-0.00161152	-0.00161152	-0.00011782	-0.00011782	-0.00310987	0.00012247	7.8487E-07	-4.6474E-05	0
-0.0068	-0.00053717	-0.00053717	-3.9272E-05	-3.9272E-05	0.00103662	-4.0824E-05	1.08E-22	1.5491E-05	0
0	0.00053717	0.00053717	3.9272E-05	3.9272E-05	0.00103662	-4.0824E-05	-7.8487E-07	1.5491E-05	0
0.00675	0.00161152	0.00161152	0.00011782	0.00011782	-0.00310987	0.00012247	-8.7995E-07	-4.6474E-05	0
0.0135	9.43E-05	0.00527744	0.00029842	9.43E-05	0	0	0	0	-0.00015491
0.02025	0.00738841	0.00013202	0.00013202	0.00041779	0	0	0	0	0.00021688
0.027									

	0	**-6.78E-19**	**-0.004146**
B=	**0**	**0**	**0.000163**
	-8.8E-07	**-6.2E-05**	**0**

D Matrix

z	D11	D12	D21	D22	D16	D26	D31	D32	D36
-0.027	0.000263608	4.71031E-06	4.71031E-06	1.4906E-05	0	0	0	0	7.73788E-06
-0.0203	2.41881E-06	0.000135366	7.65443E-06	2.41881E-06	0	0	0	0	-3.9735E-06
-0.0135	2.53814E-05	2.53814E-05	1.8556E-06	1.8556E-06	4.89805E-05	-1.9289E-06	-7.3196E-07	7.31962E-07	0
-0.0068	3.62592E-06	3.62592E-06	2.65086E-07	2.65086E-07	-6.9972E-06	2.7556E-07	1.04566E-07	-1.0457E-07	0
0	3.62592E-06	3.62592E-06	2.65086E-07	2.65086E-07	6.99721E-06	-2.7556E-07	-1.0457E-07	1.04566E-07	0
0.00675	2.53814E-05	2.53814E-05	1.8556E-06	1.8556E-06	-4.898E-05	1.92892E-06	7.31962E-07	-7.3196E-07	0
0.0135	2.41881E-06	0.000135366	7.65443E-06	2.41881E-06	0	0	0	0	-3.9735E-06
0.02025	0.000263608	4.71031E-06	4.71031E-06	1.4906E-05	0	0	0	0	7.73788E-06
0.027									

	0.0005901	**0.0003382**	**-6.78E-21**
D=	**2.897E-05**	**3.889E-05**	**4.235E-22**
	2.118E-22	**-2.12E-22**	**7.529E-06**

```
In[2]:= Inverse[(
   0.636649727      0.636649727     0               0                0               -0.004146497
   0.046544531      0.046544531     0               0                0               0.000163295
   0                0               0               -0.000000879954  -0.000061965    0
   0                0               -0.004146497    0.000590068      0.000338168     0
   0                0               0.000163295     0.0000289709     0.000038891     0
   -0.000000879954  -0.000061965    0               0                0               0.00000752875
)]

Out[2]= {{19.8758, -250.072, 0., 0., 0., 16370.6}, {-19.3259, 264.035, 0., 0., 0., -16370.6}, {0., 0., 994.513, -133.165, 2742.46, 0.},
  {0., 0., 16370.6, 765.175, 19429.8, 0.}, {0., 0., -16370.6, -10.8661, -275.92, 0.}, {-156.738, 2143.9, 0., 0., 0., -1.73863×10^-10}}
```