MECHANICAL BEHAVIORS OF COMPOSITE MATERIALS

Topic 2

Task

Finite element modeling via ABAQUS and comparing the results to the experimental work from reference paper

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1. Project task:

Finite element analysis (FEA) for dynamic behavior of composite material may provide more detailed analysis and understanding of the stress and strain distribution as well as damage situation that cannot be *in-situ* revealed by conventional test methods. Students are asked to establish a finite element model to describe the dynamic response of the sample (The laminated composite specimen is 10×10×10mm in size, which is similar to experimental cases, and is modeled with 20 stacked plies).

Reference paper: *Hu et al. Dynamic compressive behavior of woven flax-epoxy-laminated composites. International Journal of Impact Engineering 117, 63-74, 2018.*

In the Project, it expected to run the simulation as per mentioned in the papers and compare the results for 2 strain rates. The experiment was carried out for 5 different strain rates and stress strain curve is plotted accordingly. But for simulation purposes, strain versus time was plotted for in-plane and out-plane conditions.

2. Finite Element Modelling process:

A. Dimensions and modeling.

As mentioned from the reference research paper, 3 parts were modeled.

a. The striker.
b. The incident and transient bar.
c. The sample cube.

The dimensions of the bar are as follows:

BAR	DIAMETER	LENGTH
Incident and transient bar	19 mm	1200 mm
Striker	19 mm	300 mm

The Cube is a 10 mm*10 mm*10 mm stacked sample with ply of 20 samples of size 10 mm*10mm and with a thickness of 0.5 mm. the plies are arranged in 0 degree and 90-degree angle alternately.

B. Properties and parameters of the model in simulation.

The property of the bar is same for all three bars, given as:

	E(GPa)	Poisson’s ratio	Density (kg/m^3)
Bar	200	0.1	8100

As the paper mentions we are supposed to have different properties of the cube material depending on the orientation of loading, i.e. in plane or out plane loading. The following table shows what different parameters were used and their values depending on two strain rates and the orientation.
These parameters were calculated using the equations provided from the reference paper.

$$F(\dot{\varepsilon}) = F(\dot{\varepsilon}_0)\left[m \cdot \log_{10}\left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right) + 1\right],$$

F = Parameter
ε = Required strain rate i.e. 500/s and 1800/s.
ε_0 = 0.003/s strain rate.
m = Calculated value, 0.4(in-plane) and 0.53(out-plane).

Properties	Value mentioned for quasi-static	500/s In-plane	1800/s In-plane	500/s Out-plane	1800/s Out-plane
Modulus in fiber direction E1=E2 (MPa)	8000	24709.6	26489.92	30140.64	32049.85
Transverse Moduli E3 (MPa)	4300	13281.41	14238.33	16200.59	17226.79
Shear moduli G12 (MPa)	3400	10501.58	11258.22	12809.77	13621.19
Shear moduli G13=G23(MPa)	2200	6795.14	7284.728	8288.676	8813.708
Poisson's ratio v12	0.364	0.364	0.364	0.364	0.364
Poisson's ratio v13=v23	0.07	0.07	0.07	0.07	0.07
Longitudinal tensile strength X_t (MPa)	444	1371.383	1470.191	1672.806	1778.767
Longitudinal compressive strength X_c (MPa)	450	1389.915	1490.058	1695.411	1802.804
Transverse tensile strength Y_t (MPa)	19	58.685	62.913	71.584	76.118
Transverse compressive strength Y_c (MPa)	88	271.805	291.389	331.547	352.5483

Shear strength S12	30.54	94.328898	101.1252696	115.0618932	122.3502947
Shear strength S13=S23	39.13	120.860831	129.5688212	147.4254054	156.763819
Density (kg/m3)	1193	1193	1193	1193	1193
Longitudinal tensile fracture toughness G_{lt} (N/mm)	5.8	17.91446	19.205192	21.851964	23.2361398
Longitudinal compressive fracture toughness G_{lc} (N/mm)	5.8	17.91446	19.205192	21.851964	23.2361398
Transverse tensile fracture toughness G_{tt} (N/mm)	2.4	7.41288	7.946976	9.042192	9.6149544
Transverse compressive fracture toughness G_{tc} (N/mm)	2.4	7.41288	7.946976	9.042192	9.6149544

- For each of the cases the intersection criteria were same as it was a general contact.
- The boundary conditions were also same. Since the loading is in Z-axis direction the Z displacement was not constrained for any of the parts. And the striker had a velocity of 5000 mm/s for 500/s strain rate and 18000 mm/s for 1800/s strain rate.
- The mesh for each of the bar was taken to be 10 mm and that for the cube was 1mm. (shown in figure 1)

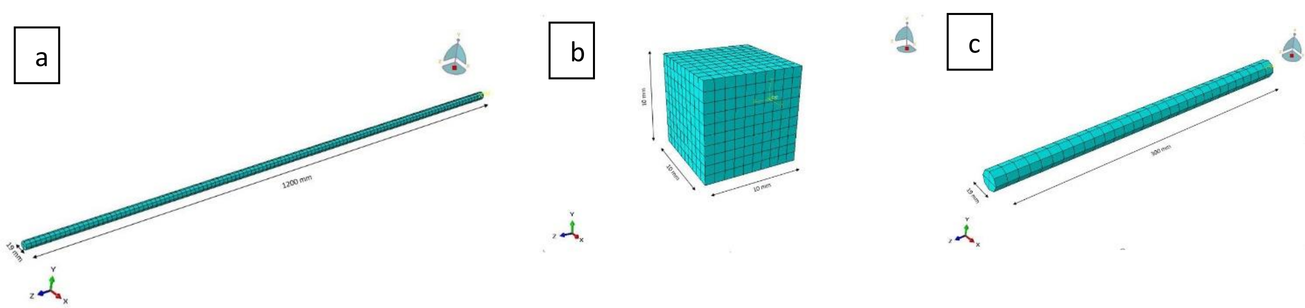

Fig.1. a. Incident and transient bar mesh, b. sample cube mesh, c. striker mesh.

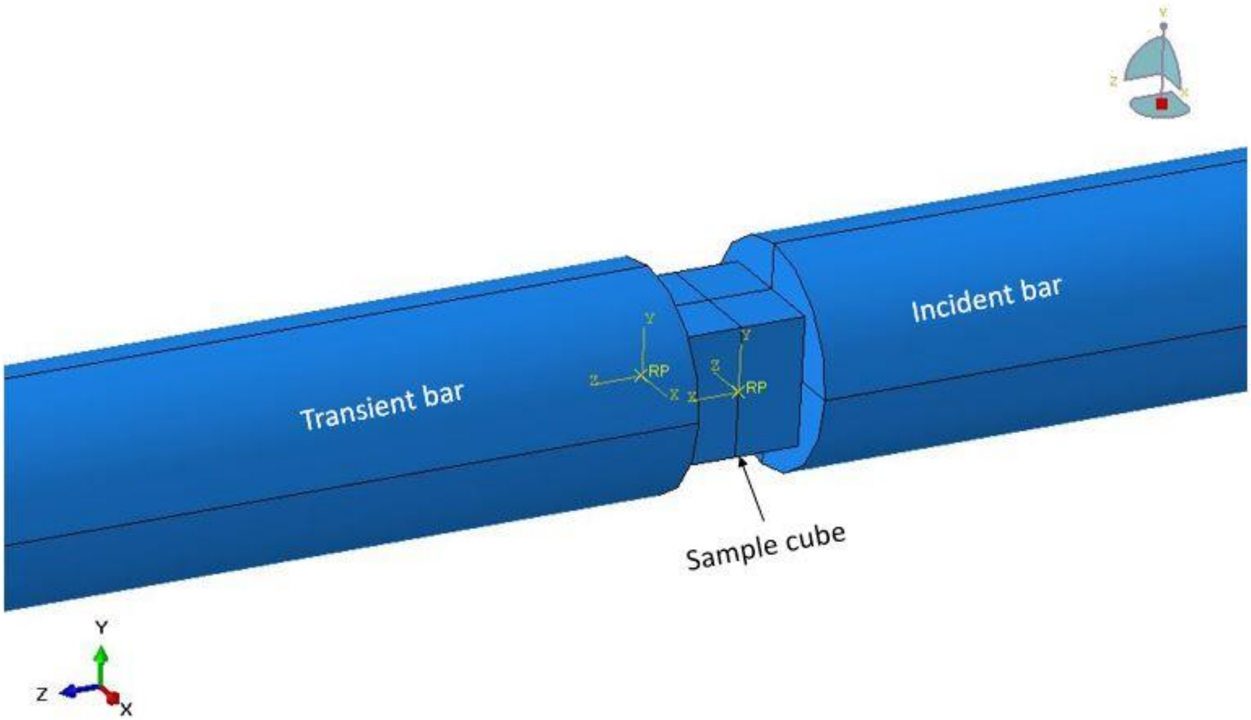

Fig.2. Mounting and positioning of the sample cube in between the incident and transient bar.

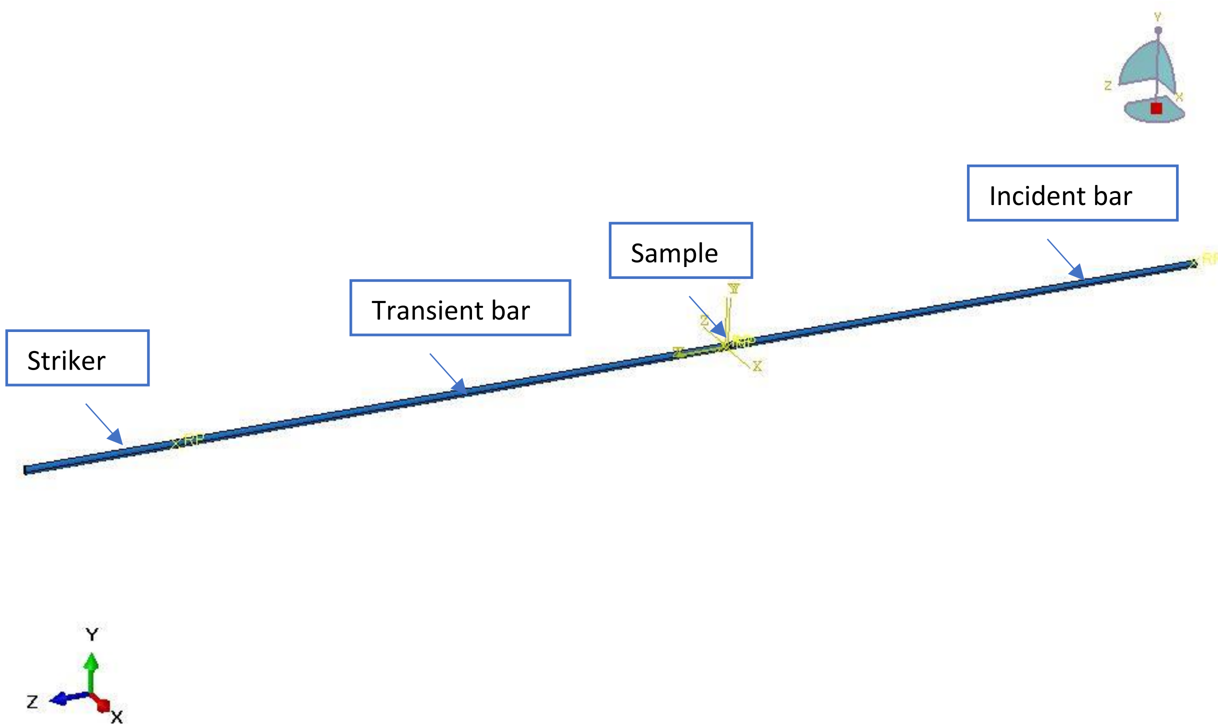

Fig.3. Overall assembly.

3. Results.

A. In-plane Compression

When the striker did strike at 5000 mm/s and 18000 mm/s speed the results for in-plane and out-plane were plotted and compared with the experimental results from the reference paper.

The plots were obtained for 2 points in the assembly. One on incident bar and other on transient bar.

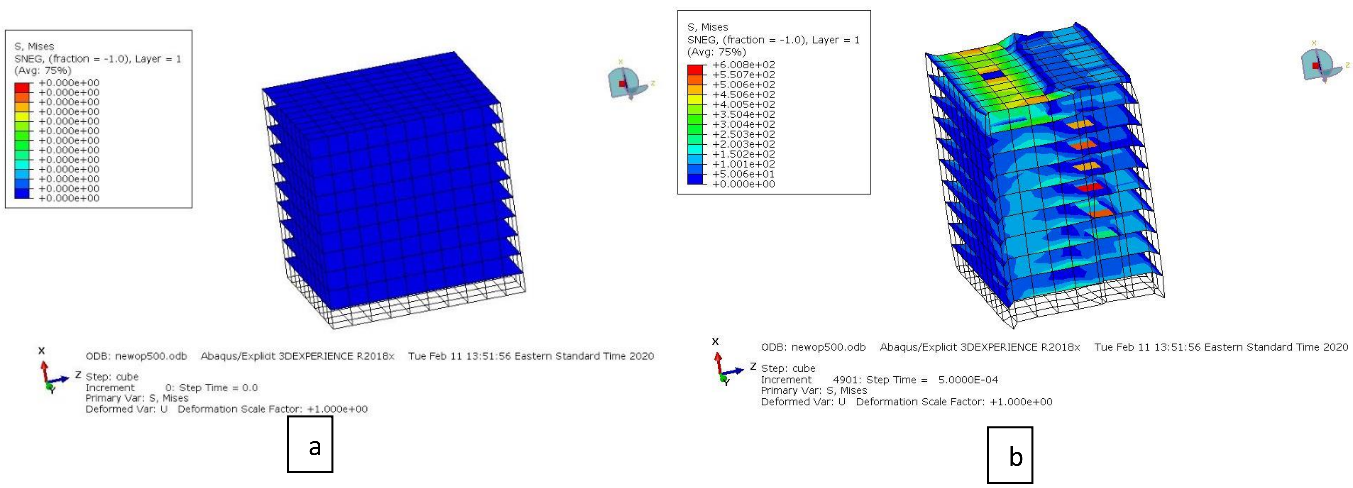

Fig.4. a. Before compression due to striking, b. After compression due to striking for in-plane compression.

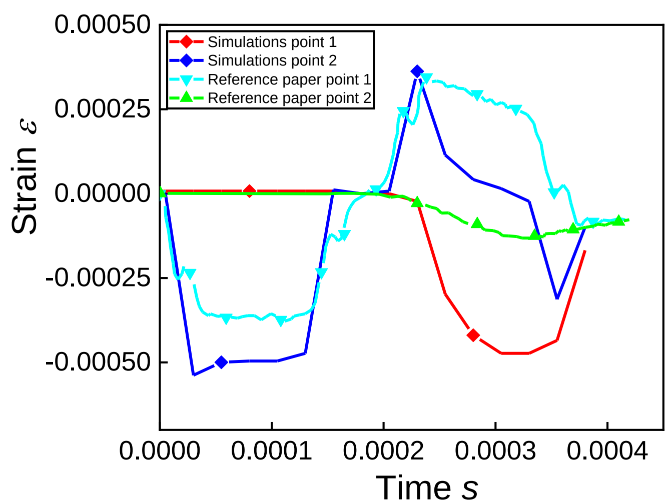

Fig.5. Strain vs time comparison of experimental and simulation results for in-plane 500/s ε.

From the comparison plots of the strain vs time from fig.5 for the 500/s in-plane compression it is observed that the simulation and experimental results almost align. The start and the increment of the strain is almost the same, the plot for experimental has vibrations at the maximum strain and then it drops as the. The point 1 plot gets a good alignment as compared to the point 2 plot. But the maximum strain obtained for both is same.

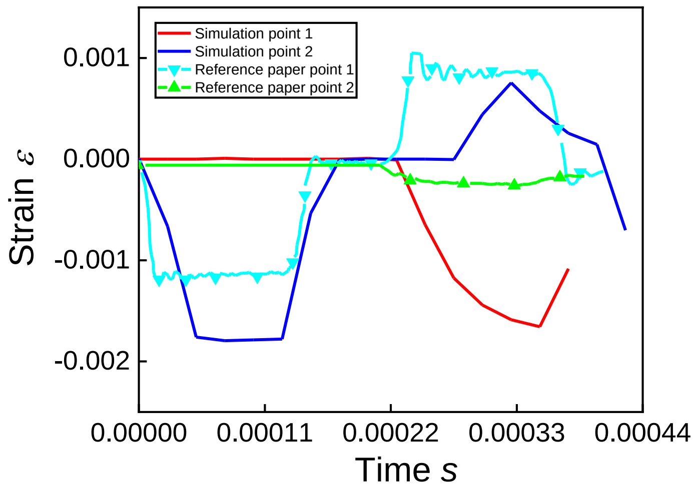

Fig.6. Strain vs time comparison of experimental and simulation results for in plane 1800/s ε.

From fig.6 which is comparison of in-plane compression for experimental and simulation results. The alignment and fitting of the plots is not that good this may because of the highspeed of the simulation and due to the mesh work. It is expected that the sample cube should take maximum strain up to 0.0007 and minimum of around -0.0012. but the experimental values go to maximum of 0.001 and the minimum of 0.002. This offset may be due to the reason that the environment in which the experiment is performed and the simulation environment.

Comparing the curves for both 500/s and 1800/s strain rates the better fit of the plots is at lower speed and lower strain rate.

B. Out-plane Compression

As for the out-plane compression of the cube sample similar to the in-plane sample the graphs are plotted for 2 points, one on incident bar and other on transient bar.

Following are the pictures and plot for comparing the out-plane compression of the cube sample.

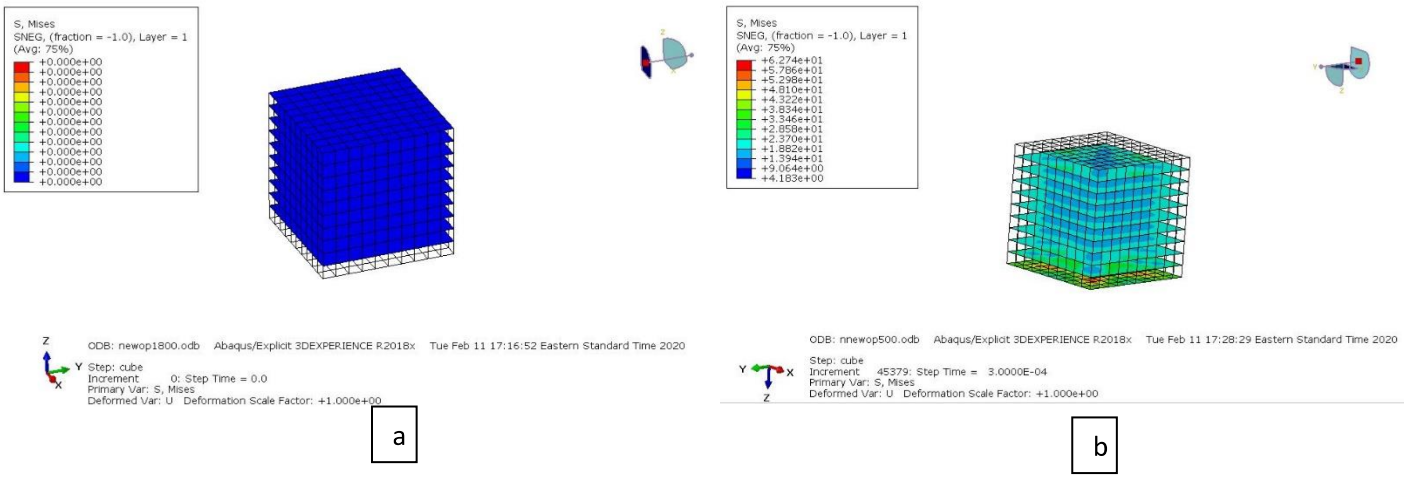

Fig.7. a. Before compression due to striking, b. After compression due to striking for out-plane compression.

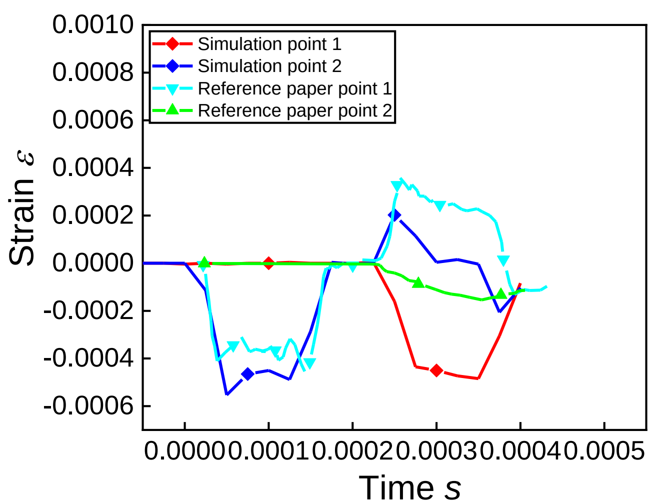

Fig.8. Strain vs time comparison of experimental and simulation results for out-plane 500/s ε.

From fig.8 it is observed that the fit for out-plane compression for plots from experiment and from simulations almost match up. But from simulations it is expected that the curve should have maximum strain of 0.0002 and minimum of about -0.0005. The experimental results show that they maximum strain is at 0.0004 and minimum strain at -0.0004. Due to the impact wave the point 2 plots receive much lower strain in simulation work but from experimental work it is clear that not a much higher energy is transferred hence resulting in a lower strain in actual experimental plot.

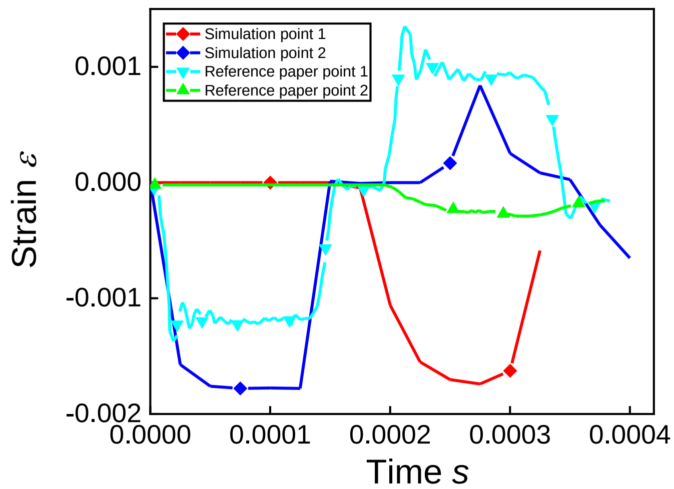

Fig.9. Strain vs time comparison of experimental and simulation results for out-plane 1800/s ε.

From fig.9 it is observed that the fit for out-plane compression for plots from experiment and from simulations almost match in the initially but later on it changes. From the simulations it is expected that the curve should have maximum strain lower than 0.001 and minimum of about -0.002. The experimental results show that they maximum strain obtained is 0.0015 and minimum strain at -0.0014. Similar condition as the previous case, due to the strain energy the minimum strain for point 2 is much lower than the strain obtained from experiment. The experimental plot show a pitching up and down due to actual vibration wave flowing through the bars.

Overall comparing the results and the plots, the out-plane compression for the sample cube is requires more force for compression and yet the displacement is less. But for in-plane compression for the sample less force gives out more displacement as compared to out-plane compression. Even though the contact area is same the orientation of the sample does play an important role in understanding the failure and fracture of the cube.

4. Conclusion

Using the reference research paper [1] a model of the experimental setup was used for comparing and simulation and experimental results. The simulation used the Hashin damage criteria to detect the failure of the sample cube model. The cube was modeled and given properties as per the different strain rates and also as per the orientation i.e. in-plane and out-plane loading. The results comparison shows that at lower strain rate the plots gets matched up pretty well as compared to those at higher strain rate. Due to the environment of the experiment and the set up there are offsets in the simulation and the experimental results. More force is needed for out-plane compression than the in-plane compression.

Reference

[1] *Hu et al. Dynamic compressive behavior of woven flax-epoxy-laminated composites. International Journal of Impact Engineering 117, 63-74, 2018*.