UNC CHARLOTTE

The WILLIAM STATES LEE COLLEGE of ENGINEERING

Numerical Simulations in Mechanical Engineering

Project I

Mechanical response of lithium-ion battery upon abusive loading

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1. Introduction

Lithium-ion batteries (LIBs) are highly essential to various mechanical systems from large-scale of hybrid electric vehicle (HEV), and pure electric vehicle (EV) to small portable devices such as cell phones and microchips. In particular, LIB has been regarded as one of the best energy densities available in automobiles today, where it sustains continuous dynamic loadings at various frequencies caused by the road-vehicle interactions, as well as possible harmful collisions from traffic accidents. Capacity or properties fading, short-circuit induced thermal problems, fire or severe explosions, along with mechanical integrity problems are unwanted consequences and threatens to electric vehicle safety. Therefore, increasing attention has been attracted to focus on the study of LIB mechanical integrity. Our task for this project is to study the mechanical response of lithium-ion batteries upon abusive loading.

In this Project we are supposed to carry out five simulation tests to study the response of the battery, they are:

1. Bend R30 (Skin only)
2. Compression
3. Indentation
4. Bend R30 (Whole cell)
5. Axial Compression

2. Finite Element Modelling Process

2.1. Model Details

The battery model selected for these test is Cylindrical Nickel Cobalt Oxide (NCA) Lithium-ion cells (GAIA, HP 602030 NCA-45 A/162 Wh). The dimensions of this cell can be seen in figure 1.

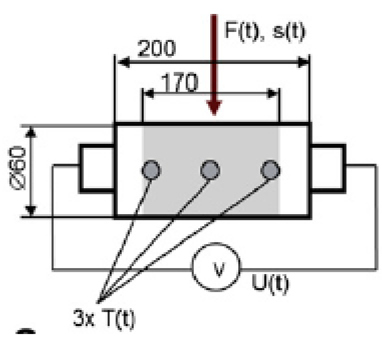

Figure 1 Battery Dimensions [1]

Properties

	Young's Modulus (MPa)	Density (Ton/s)
Jelly Roll	1500	3.12×10^{-9}
Shell	207000	7.88×10^{-9}

The dimensions of the battery model are, the outer shell is 200mm long, 60mm diameter, and the jelly roll is 170mm long and 57mm diameter. Interaction criteria was given on all surfaces. The coefficient of friction value taken is 0.1.

The step value was taken according to the time step given in the paper [1] as one micro-second. We choose a displacement model as we needed constant velocity.

The equations used for defining the yield stress and strain were taken from the paper [1]

For housing or the shell of the battery:

$$R_{\text{housing}}(\overline{\varepsilon}^p) = k(\varepsilon_0 + \overline{\varepsilon}^p)^n, \qquad \text{- (1)}$$

For the jelly roll:

$$R(\overline{\varepsilon}^p) = \left[\sigma_{\text{plateau}} - \left(\sigma_{\text{plateau}} - \sigma_{\text{yield}}\right) \times Exp\left(-\frac{\overline{\varepsilon}^p}{\overline{\varepsilon}_{\text{ref}}}\right)\right] \times \left[1 + s(\overline{\varepsilon}^p)^m\right]. \qquad \text{- (2)}$$

For the above equations the value of plastic strain was taken starting from zero with an increment of 0.1 to find the value of corresponding yield stress.

2.2 Mesh Criteria

A coarse mesh was used for all these simulations as it requires less time to simulate. We tired simulating with two different mesh size, 5mm and 10mm. The results obtained from both these simulation did not show a significant change. Hence to increase the speed of the simulations we settled with a 10mm mesh size. All the results in this report are from 10mm mesh size.

3. Tests

3.1 Bend R30 (Skin only)

The setup for this test is as seen in figure 2, it is a three point bending system.

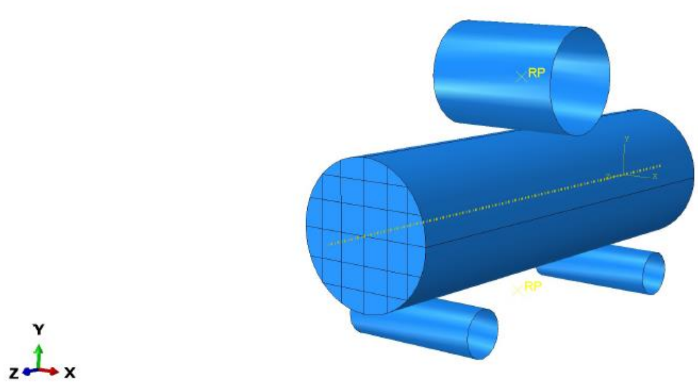

Figure 2 Assembly setup for Bend test

The rollers at the bottom are fixed (rigid body), the top roller (rigid body) moves only in y-direction. The shell is not constrained completely, it is constrained only at the end points. The maximum displacement of the top roller is 70mm.

3.1.1. Results

Figure 3a & 3b represent the final image of battery after the test is completed, in full section and half section respectively. As expected the tabs of the battery experience the most compressive force. Figure 4 represents the graph of the bend test carried in our simulation with graph of the bend test done by Greve L, Fehrenbach C in 2012 [1]. From the graph we can interpret that the trend followed by the simulation conducted by us is very similar to that of Greve et.al, the graph aligns well in the starting, then we see two peaks in our plot, the reason for that is when we apply a constant force at the shell, the middle part flattens while the side points harden. As the shell is empty, the hard point experience a higher load. The second reason for the results not aligning properly is because the mesh we used for simulation is course, if we use a more refined mesh we can expect the results to align better.

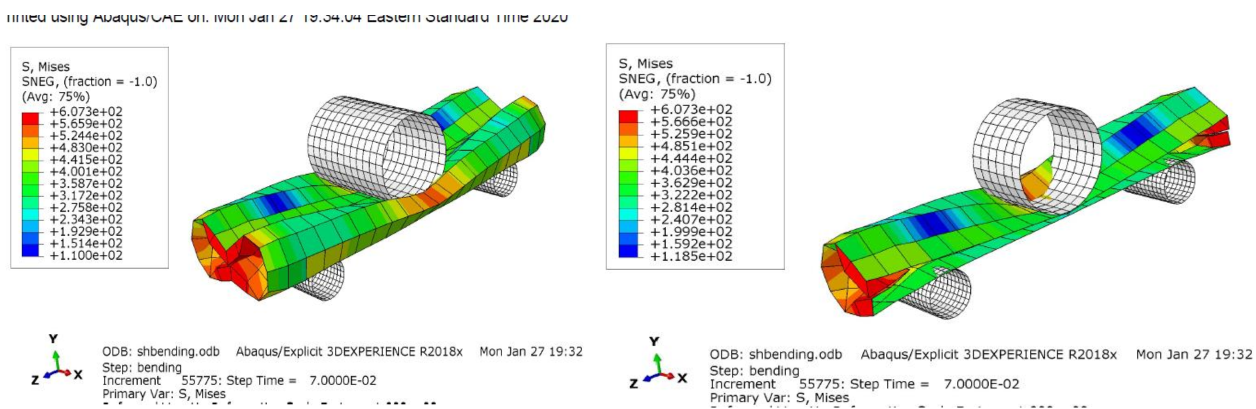

Figure 3 Bend test (skin only) – a) Full shell, b) half shell

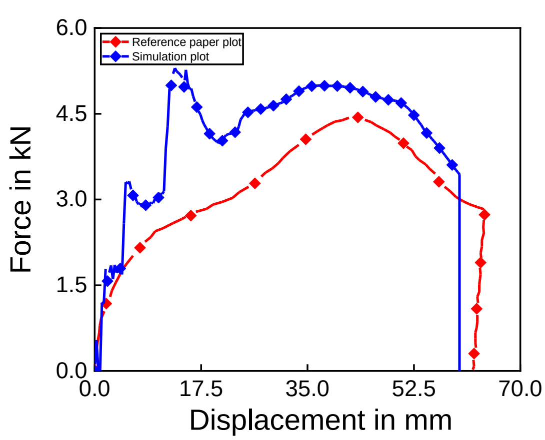

Figure 4 Bend test (skin only) - the plot shows the results of the simulation compared with the reference paper plot [1]

3.2 Compression Test

The setup for this test is shown in figure 5, we have a fixed (rigid body) under-plate and a rigid body plate which moves with a constant velocity. The battery is deformable.

The plate has a maximum displacement of 30mm in the y-direction. The lower plate is fully constrained, whereas the battery is line constrained.

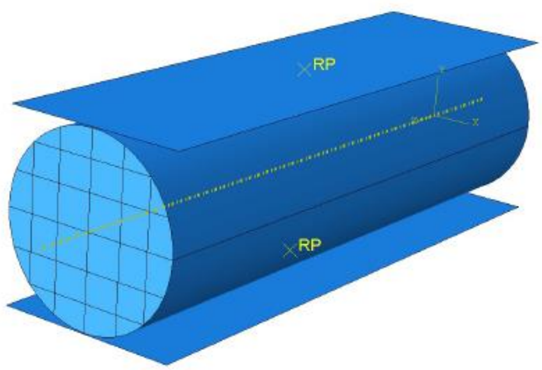

Figure 5 Test setup for compression test

3.2.1. Results

Figure 6a and 6b represent the sectional view of the jelly roll and, shell and jelly roll respectively. The compressive stresses experienced by the shell and jelly roll are visible. Figure 7 represents a fully compressed battery. The displacement of the plate at the instant is 30mm in the Y-direction.

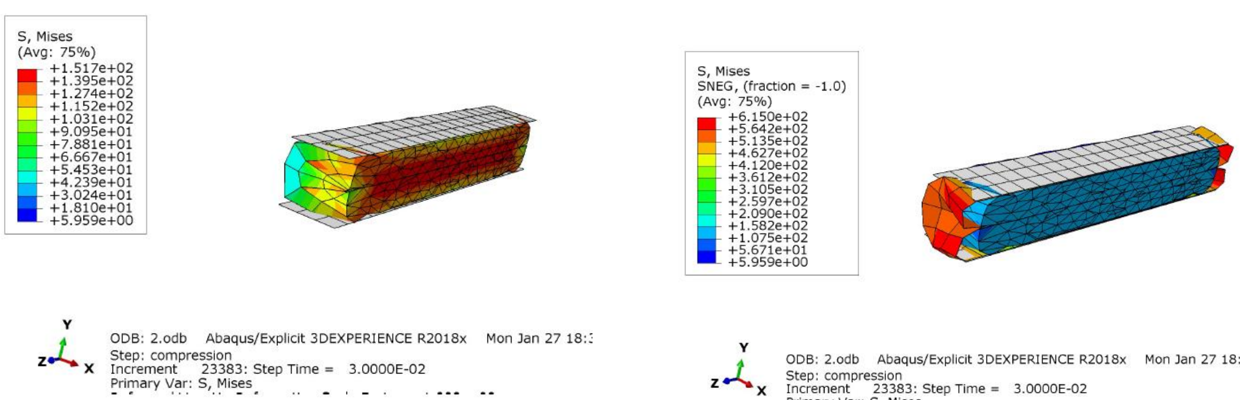

Figure 6 Compression test results a) Jelly roll under compression b) The shell and jelly roll under compression

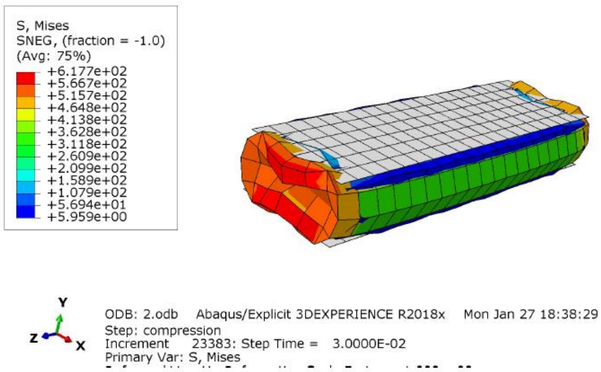

Figure 7 fully compressed battery

The graph shows a very good alignment of the simulation conducted by us and the result from the reference paper. The model fractures at around 23 mm displacement. The peak of the simulation reaches faster than the reference model but the load in our simulation is higher.

The reason for this may be due to the stiffness that occurs under loading of the battery cell and due to the mesh size considerations as well.

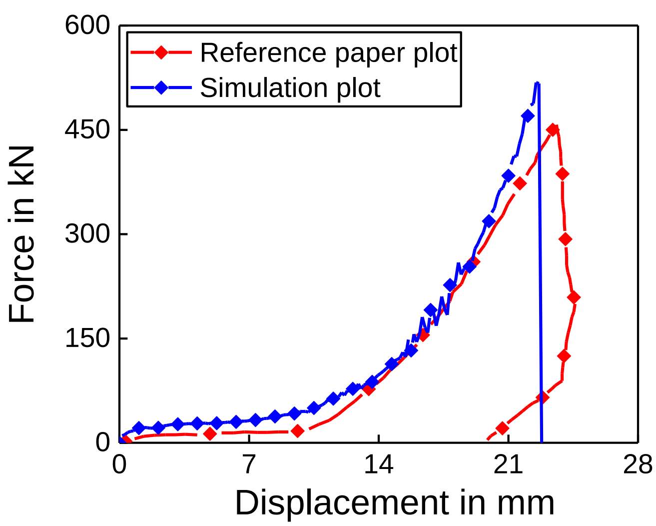

Figure 8 Graph of Compression test plotted with the reference plot [1]

3.3 Indentation Test

The setup for this test is shown in figure 9. The setup consists of an indenter, which we took as a rod of diameter 30 mm. The bottom plate is a fixed rigid body. The body is constrained along a line. The indenter moves by 25mm in the y-direction.

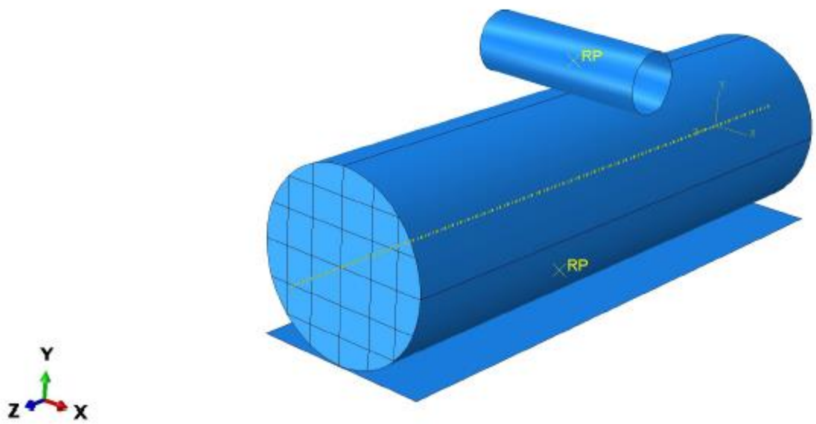

Figure 9 Setup for Indentation Test

3.3.1. Results

In the results plotted below we can see the post simulation pictures of the indentation test. The first included the shell and jelly roll whereas the second one is just the jelly roll. The value of von mises stress right below the indentation point is quite large which is to be expected.

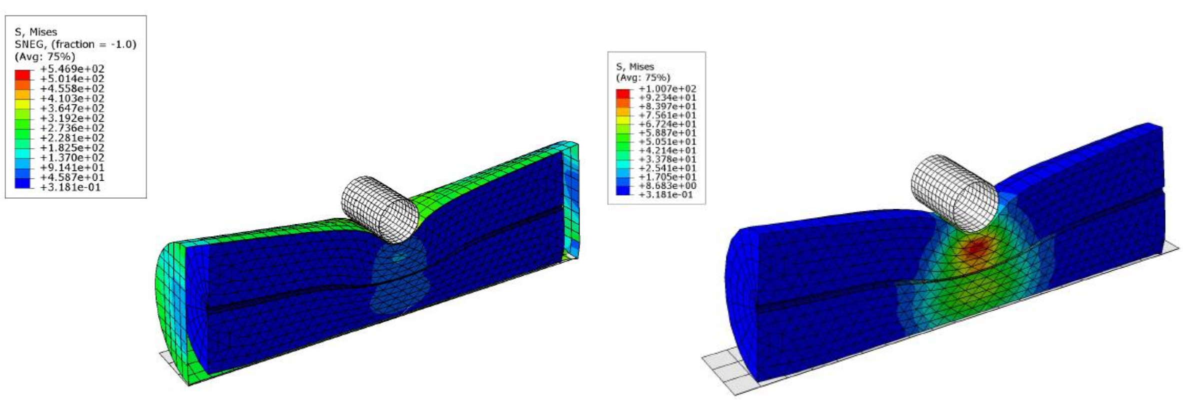

Figure 10 Indentation result for a) Shell and jelly roll b) jelly roll

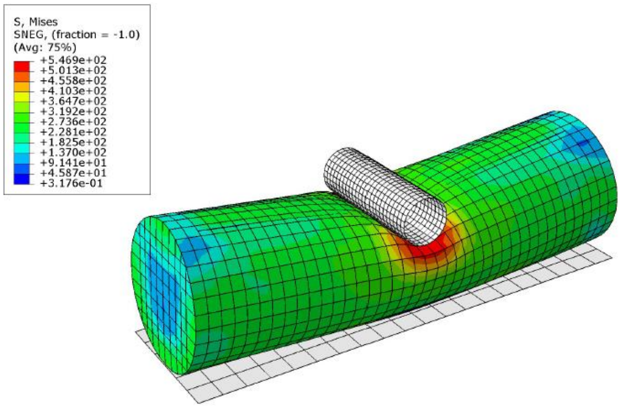

Figure 11 Indentation results for a complete battery

The graph plotted below shows the force vs displacement plot of the simulation and the reference paper. The plot matches very well in the initial stages. The graph follows a very similar trend to the reference paper. The peak of the simulation is much higher than the reference paper. The battery fractures around 25mm of displacement. Unlike the reference model we cannot see any kinks at the peak value. The simulation model failure occurs at a higher value as it should because of the displacement boundary condition provided to the model.

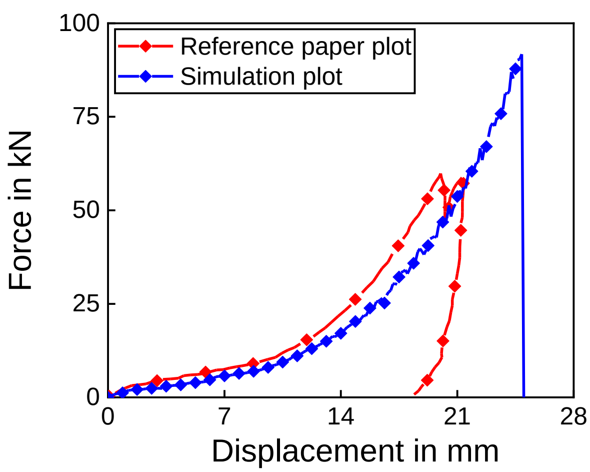

Figure 12 Indentation results plots

3.4 Bend (R30) – whole cell

The setup for this case is same as the setup of the 1st case, we use a full battery cell instead of just the shell. The results get affected by the presence of the jelly roll. The top roller is a rigid body which is allowed to move in the y-direction only, the bottom two rollers are fixed. The cell is constrained only at the end points. The roller has a maximum displacement of 60 mm.

The setup looks like the one presented in figure 13

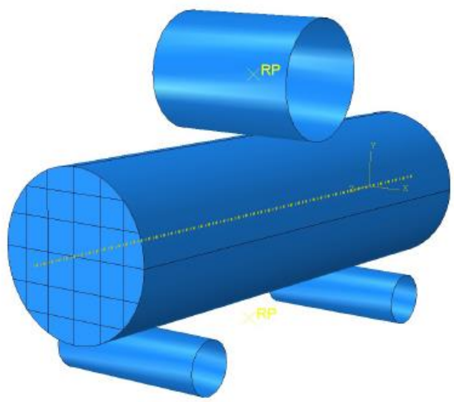

Figure 13 Bend – whole cell – setup

3.4.1. Results

Figure 14a and 14b represent the result plots, we can see from the plots the battery tabs are under most stress. The points just below the roller experience high value of stresses as well.

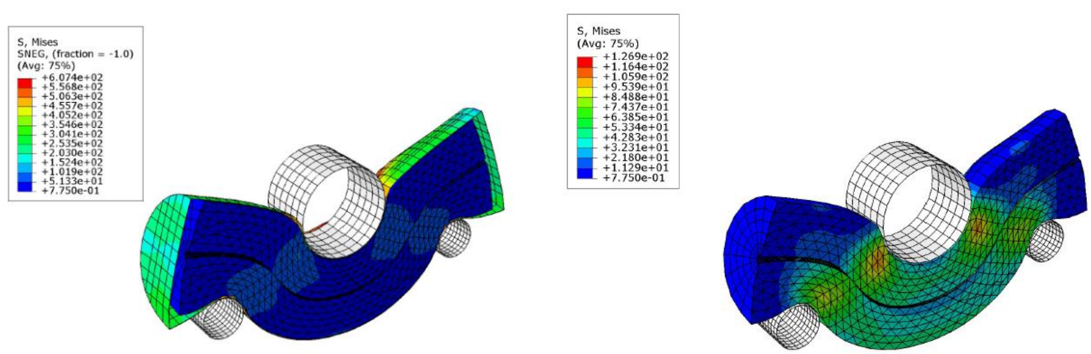

Figure 14 Bend results for the whole cell, a) with jelly roll and shell b) jelly roll

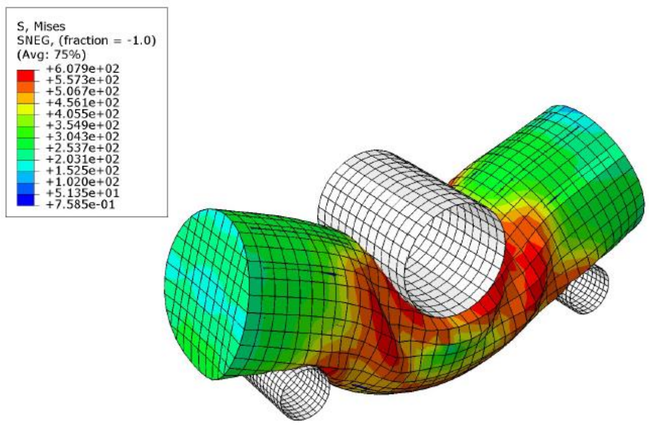

Figure 15 Bend results for the whole cell

The graph below compares the result of the numerical simulation and the reference paper results. The peak value of the simulation is higher than the reference paper. The simulation results do not go along with the reference paper results from around 15 mm displacement. The reason for which can be given with the contact condition and friction coefficient. The thickness of the shell also matters since it was not mentioned, the thickness of shell is considered to be as 1mm. During fracture the load is maximum due to increase in stiffness of battery model.

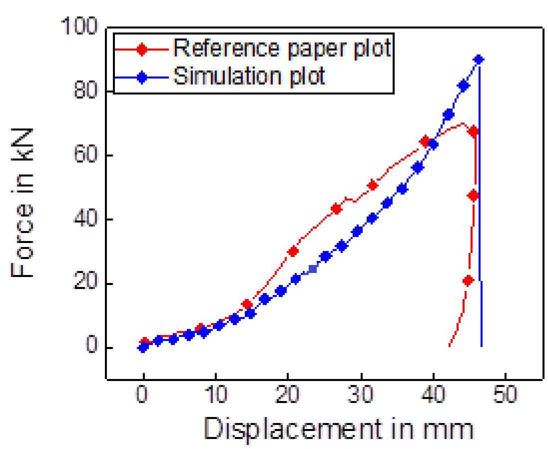

Figure 16 Plot of bend results for the whole cell

3.5 Axial Loading

The set up for this simulation is represented in the figure 17. The setup included a complete battery, two plates, the battery is placed vertically and load at constant velocity is applied. The maximum displacement is taken to be 60mm

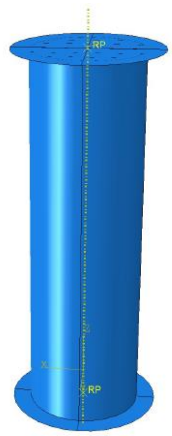

Figure 17 Axial loading setup

3.5.1. Results

The results shown in figure 18a and 18b, we can see that the shell is compressed more than the jelly roll which is expected as the height of the shell is more. The battery diameter is increasing at the edges.

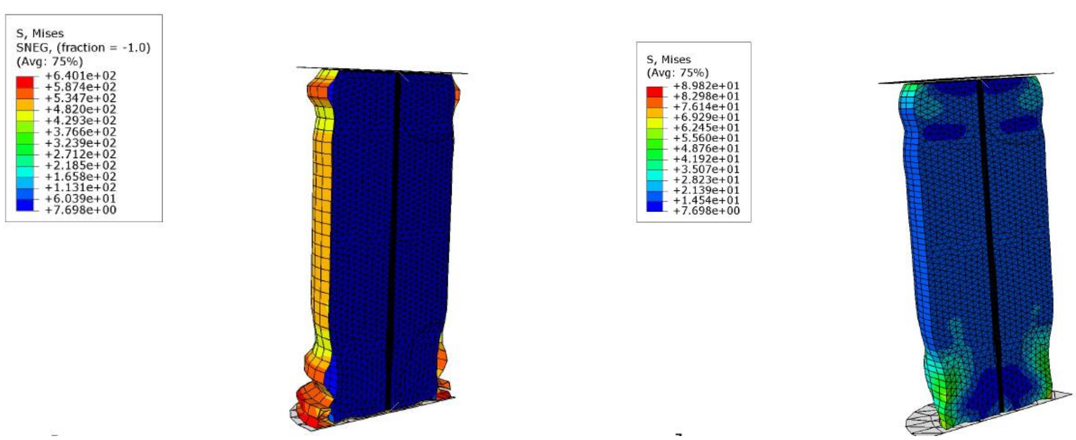

Figure 18 Axial loading result for a) with shell and jelly roll b) jelly roll

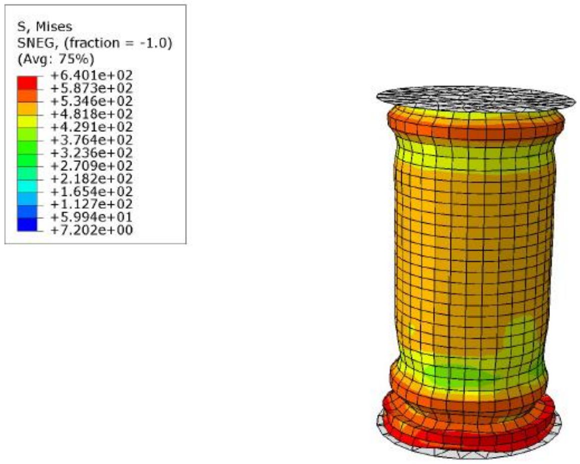

Figure 18 Axial loading result for the complete battery

Below is the graph of the Displacement vs force in axial loading condition. It is observed as the battery undergoes axial compression it starts to buckle and the load starts to increase at that instance later with increment in the displacement the material which is soft and uncompressed requires less load hence a drop in force is observed. When the material becomes stiffer, we see increase in load. From the figure it is also observed the buckling starts from bottom of battery and later propagated to the top. But with the region without jellyroll easy bucking and less load is required at the initial stage in the graph.