# Flip-Chip Package Analysis

Model 6 – Complete and Incompletely filled

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# Table of Contents

# List of Figures:

# List of Tables:

# Introduction

This project focuses on understanding the fatigue life of solder ball in a flip-chip package. Geometry for the model has been provided and for simplicity has been modified into quarter and half for complete and incompletely filled simulations. Model 6 was assigned where only the middle and right solder balls have voids around them (see below (b)). Material properties for silicon (elastic), FR-4 (elastic), solder and underfill (strain rate dependent) were also provided. Cylic thermal loading occurred from -40 to 125 °C for 12 cycles.

**Gaps are peripheral at surfaces of solder balls**

(a) Completely Filled          (b) Incompletely Filled (Case VI)

*Figure 1 Model 6 Illustration*

# Mesh

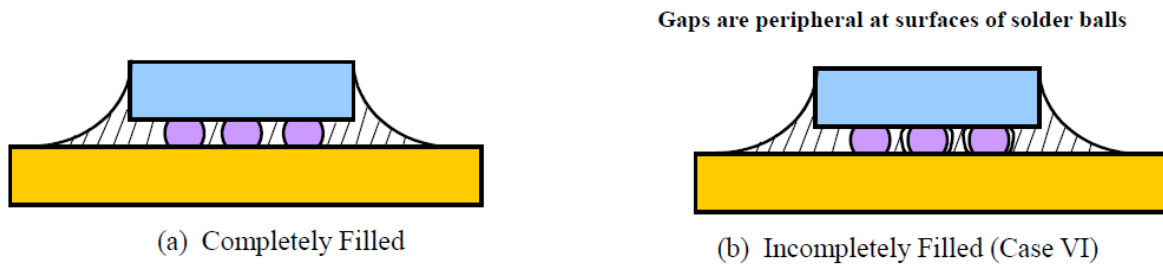C3D10 elements were created and each component was carefully meshed so that the nodes were connected at the mating face. Equivalence was applied to ensure consistency. Nodes were more concentrated with a finer mesh at the corner of the solder balls (red circles) as instructed. The completely filled quarter model mesh is shown below:
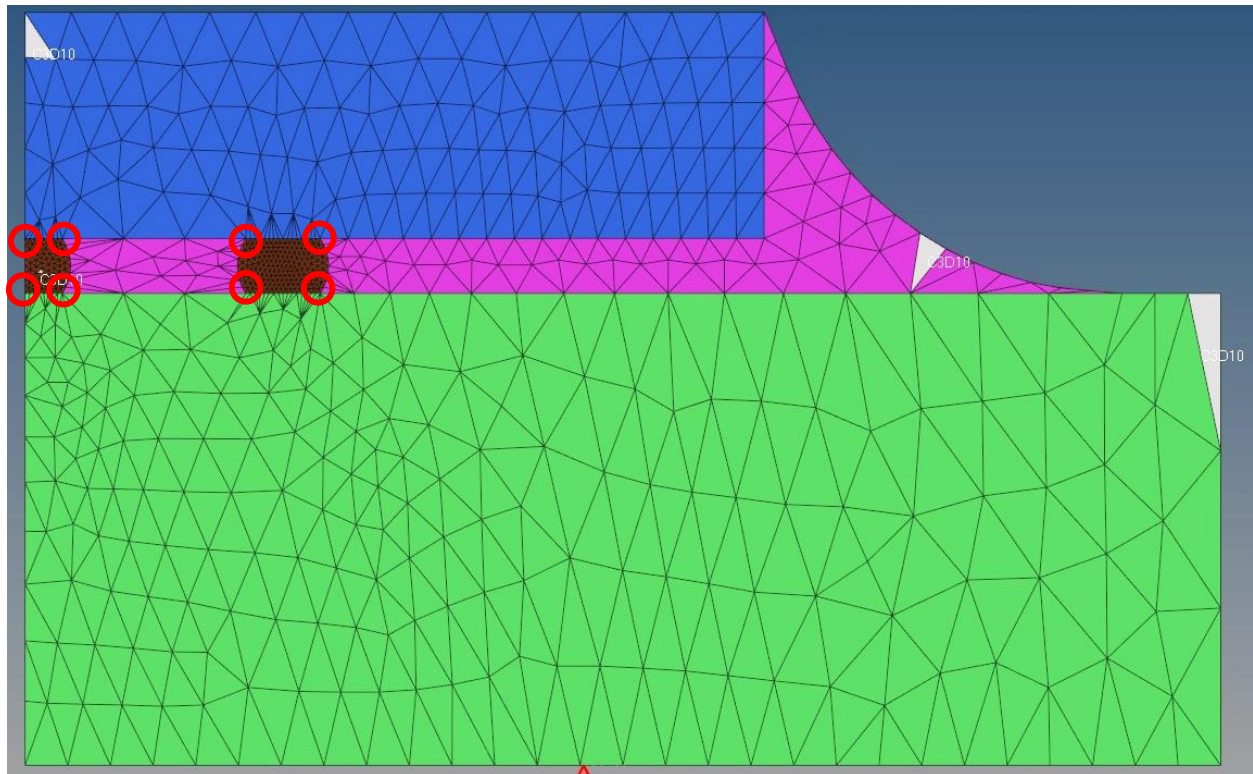
*Figure 2 Meshed (connected) of Completely Filled Quarter Model*
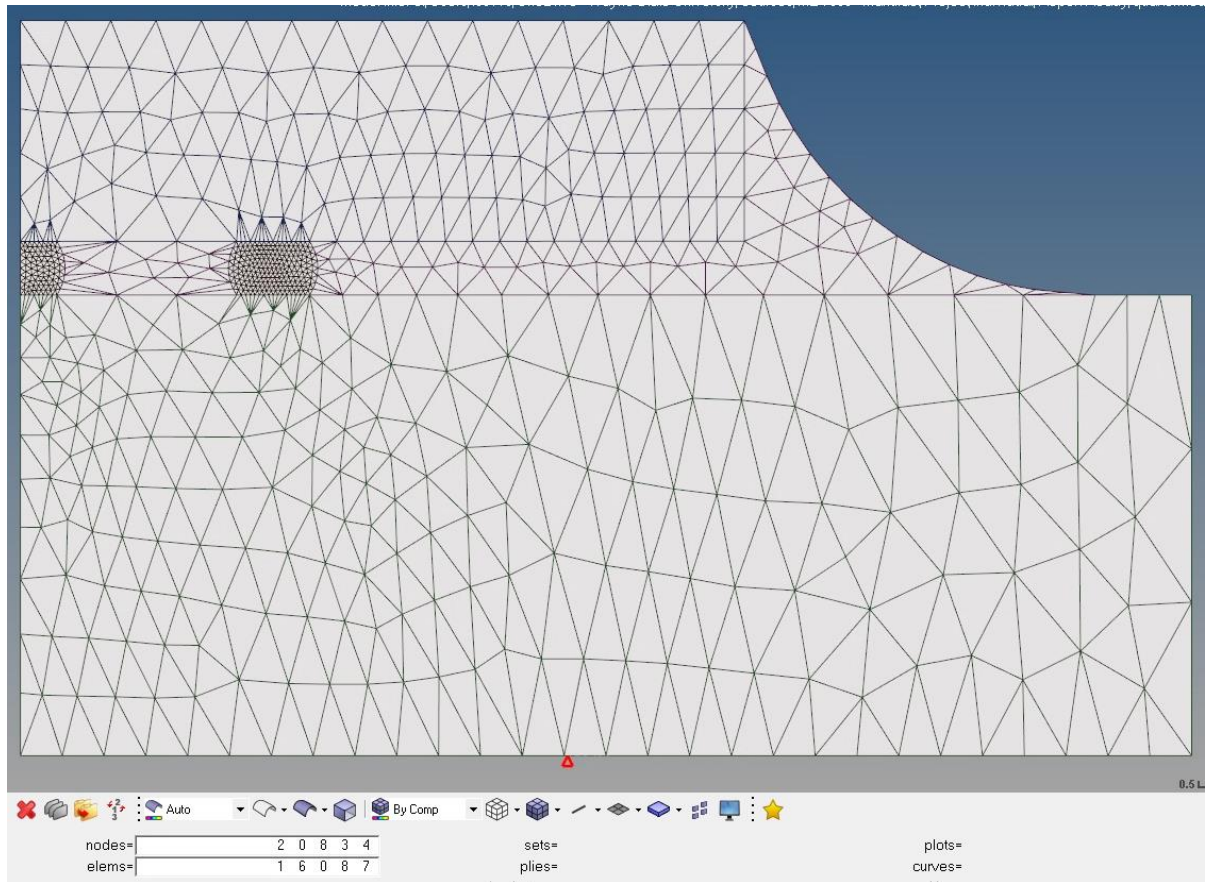
*Figure 4 Nodes (20834) and elements (16087) of Completely Filled Quarter Model*

The Incompletely filled half model mesh is shown below:
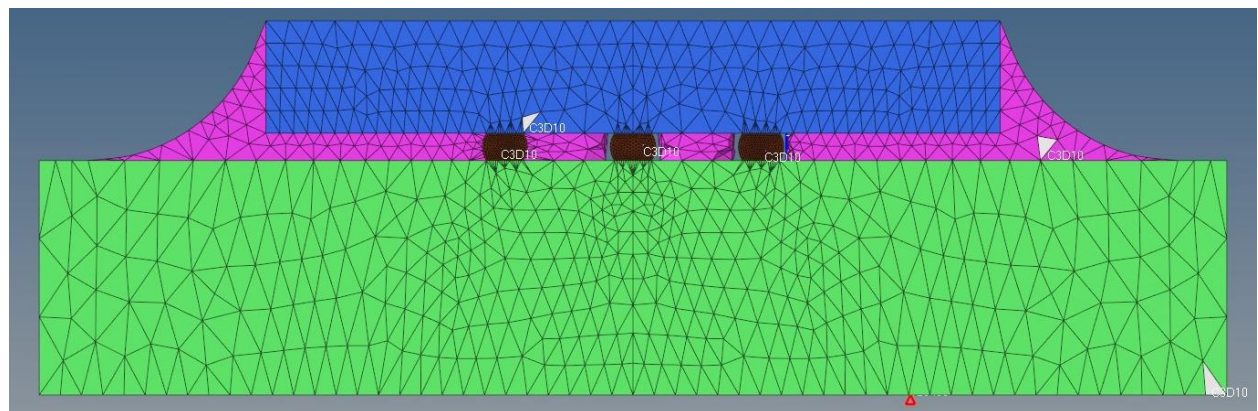


*Figure 3 Meshed (connected) Incompletely Filled Half Model*

*Figure 5 Nodes (40296) and Elements (31320) of Incompletely Filled Quarter Model*

## Boundary Conditions

The base of the flip-chip was constrained on all degrees of freedom and each node had temperature applied to it depending on the cycle. Room temperature was set at 27 C for the first initial cycle (See below).



*Figure 6 Illustration of 12 Cycles Ranging from -40 to 125 °C*

Figure 7 Boundary Constraints applied. Note the constrained surface on the bottom. Temperature constraints are applied to all nodes.
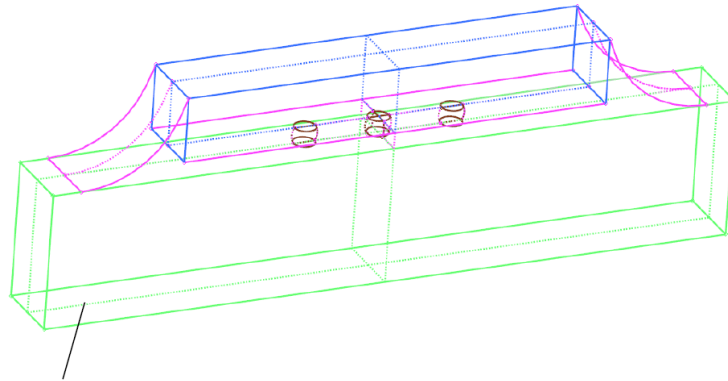
Constrain the bottom surface

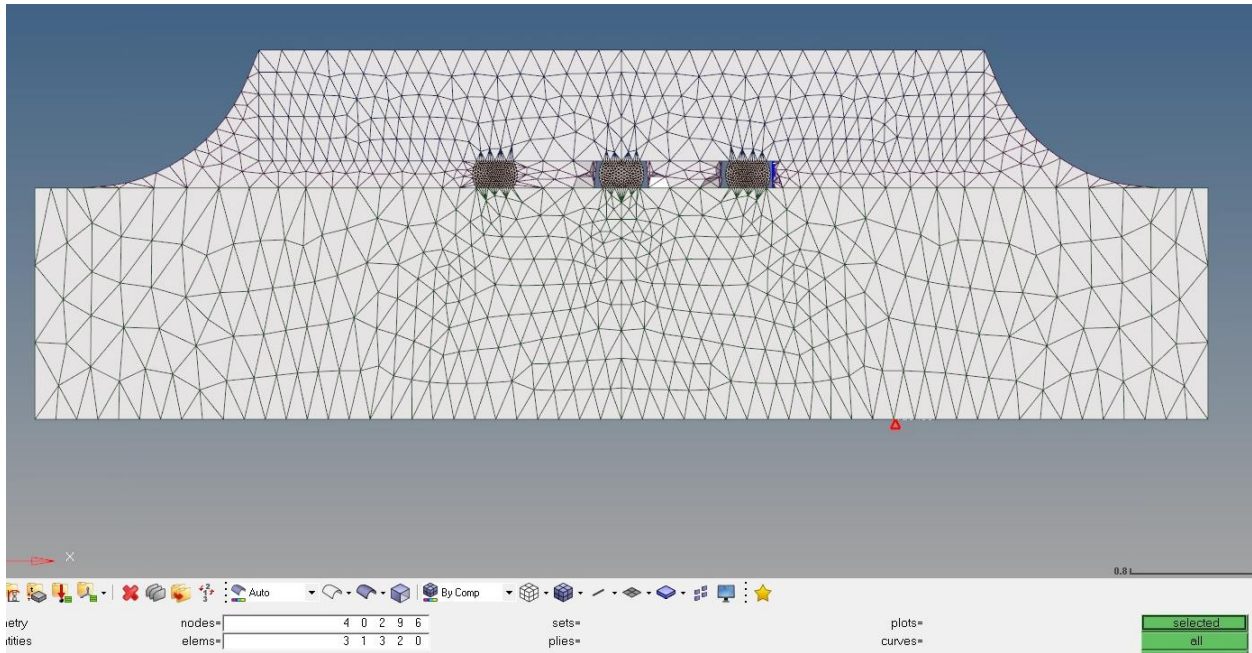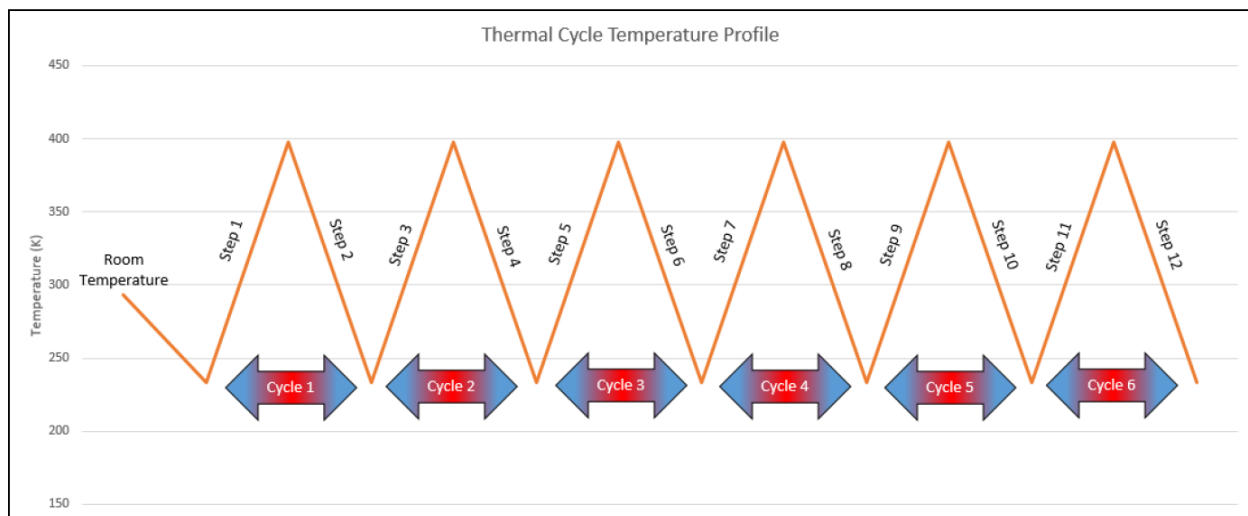Below is an image illustrating the incompletely filled flip-chip half model constraints in Abaqus. The squares represent temperature, and the bottom surface can be seen with constraints on all degrees of freedom.
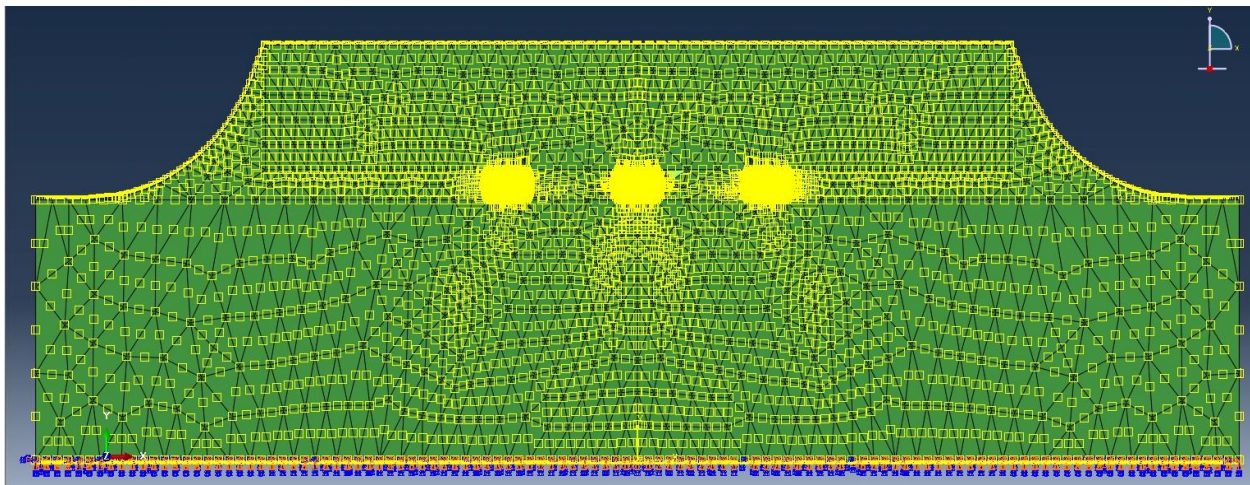


Figure 8 Illustration of Boundary Conditions in Abaqus. Squares are temperatures and the bottom surfaces are constraints on all degrees of freedom.

## Results

Fatigue Life Equation (Coffin-Manson):

$$(N_f)^\beta \Delta\gamma^p = C^p$$

$C^p$ = 1.14 and $\beta$ = 0.51
$\Delta\gamma^p$ = Applied Plastic/inelastic strain range (PEEQ)
$N_f$ = Fatigue Life

Note: Results of $\Delta\gamma^p$ for can be seen in the tables on the next page. Below are the calculated fatigues.

Completely Filled Quarter Model:

$$(N_f)^\beta \Delta\gamma^p = C^p$$

$$(N_f)^{0.51} * 0.7206 = 1.14 = \textbf{2.45}$$

Incompletely Filled Half Model:

$$(N_f)^\beta \Delta\gamma^p = C^p$$

$$(N_f)^{0.51} * 0.268 = 1.14 = \textbf{17.09}$$

Table 1 Completely Filled Quarter Model Results for Max Von Mises, Principal and Equivalent Strain (PEEQ)

| Model 6 | | | Completely Filled Quarter Model | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Max Von Mises | | Max Principal | | PEEQ | |
| | | | Timestep | | Timestep | | Timestep | |
| Step | Cycle | Temp (°C) | 0 | 1 | 0 | 1 | 0 | 1 |
| 1 | | 27 | 0.00 | 56.04 | 0.00 | 61.76 | 0.00 | 0.0023 |
| 2 | | -40 | 56.04 | 65.97 | 61.76 | 178.40 | 0.0023 | 0.0113 |
| 3 | 1 | 125 | 65.97 | 80.52 | 178.40 | 387.10 | 0.0113 | 0.0762 |
| 4 | 2 | -40 | 80.52 | 72.87 | 387.10 | 229.20 | 0.0762 | 0.1330 |
| 5 | 3 | 125 | 72.87 | 74.01 | 229.20 | 328.20 | 0.1330 | 0.1922 |
| 6 | 4 | -40 | 74.01 | 72.87 | 328.20 | 233.90 | 0.1922 | 0.2503 |
| 7 | 5 | 125 | 72.87 | 74.97 | 233.90 | 173.10 | 0.2503 | 0.3094 |
| 8 | 6 | -40 | 74.97 | 72.90 | 173.10 | 237.30 | 0.3094 | 0.3678 |
| 9 | 7 | 125 | 72.90 | 75.31 | 237.30 | 176.00 | 0.3678 | 0.4268 |
| 10 | 8 | -40 | 75.31 | 72.91 | 176.00 | 240.10 | 0.4268 | 0.4854 |
| 11 | 9 | 125 | 72.91 | 100.00 | 240.10 | 177.90 | 0.4854 | 0.5440 |
| 12 | 10 | -40 | 100.00 | 72.97 | 177.90 | 242.40 | 0.5444 | 0.6030 |
| 13 | 11 | 125 | 72.97 | 100.10 | 242.40 | 179.20 | 0.6030 | 0.6620 |
| 14 | 12 | -40 | 100.10 | 73.01 | 179.20 | 244.20 | 0.6620 | 0.7206 |
| Last Time Step Value | | | 73.01 | | 244.20 | | 0.720600 | |

Table 2 Incompletely Filled Half Model Results for Max Von Mises, Principal Stress and Equivalent Strain (PEEQ)

| Model 6 | | | Incompletely Filled Half Model | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Max Von Mises | | Max Principal | | PEEQ | |
| | | | Timestep | | Timestep | | Timestep | |
| Step | Cycle | Temp (°C) | 0 | 1 | 0 | 1 | 0 | 1 |
| 1 | | 27 | 0.00 | 54.05 | 0.00 | 39.47 | 0.00 | 0.0010 |
| 2 | | -40 | 54.05 | 71.40 | 39.47 | 127.70 | 0.0010 | 0.0047 |
| 3 | 1 | 125 | 65.97 | 80.52 | 127.70 | 145.00 | 0.0047 | 0.0281 |
| 4 | 2 | -40 | 79.64 | 85.96 | 145.00 | 176.30 | 0.0281 | 0.0493 |
| 5 | 3 | 125 | 85.96 | 81.11 | 176.30 | 128.30 | 0.0493 | 0.0715 |
| 6 | 4 | -40 | 81.11 | 86.07 | 128.30 | 182.90 | 0.0715 | 0.0931 |
| 7 | 5 | 125 | 86.07 | 81.43 | 182.90 | 122.60 | 0.0931 | 0.1152 |
| 8 | 6 | -40 | 81.43 | 86.09 | 122.60 | 185.50 | 0.1152 | 0.1370 |
| 9 | 7 | 125 | 86.09 | 81.59 | 185.50 | 119.50 | 0.1370 | 0.1590 |
| 10 | 8 | -40 | 81.59 | 86.10 | 119.50 | 186.80 | 0.1590 | 0.1808 |
| 11 | 9 | 125 | 86.10 | 81.68 | 186.80 | 117.40 | 0.1808 | 0.2209 |
| 12 | 10 | -40 | 81.68 | 86.12 | 117.40 | 187.40 | 0.2029 | 0.2247 |
| 13 | 11 | 125 | 86.12 | 81.75 | 187.40 | 115.90 | 0.2247 | 0.2467 |
| 14 | 12 | -40 | 81.75 | 86.11 | 115.90 | 187.80 | 0.2467 | 0.2686 |
| Last Time Step Value | | | 86.11 | | 187.80 | | 0.268600 | |

Critical location for completely filled quarter model:
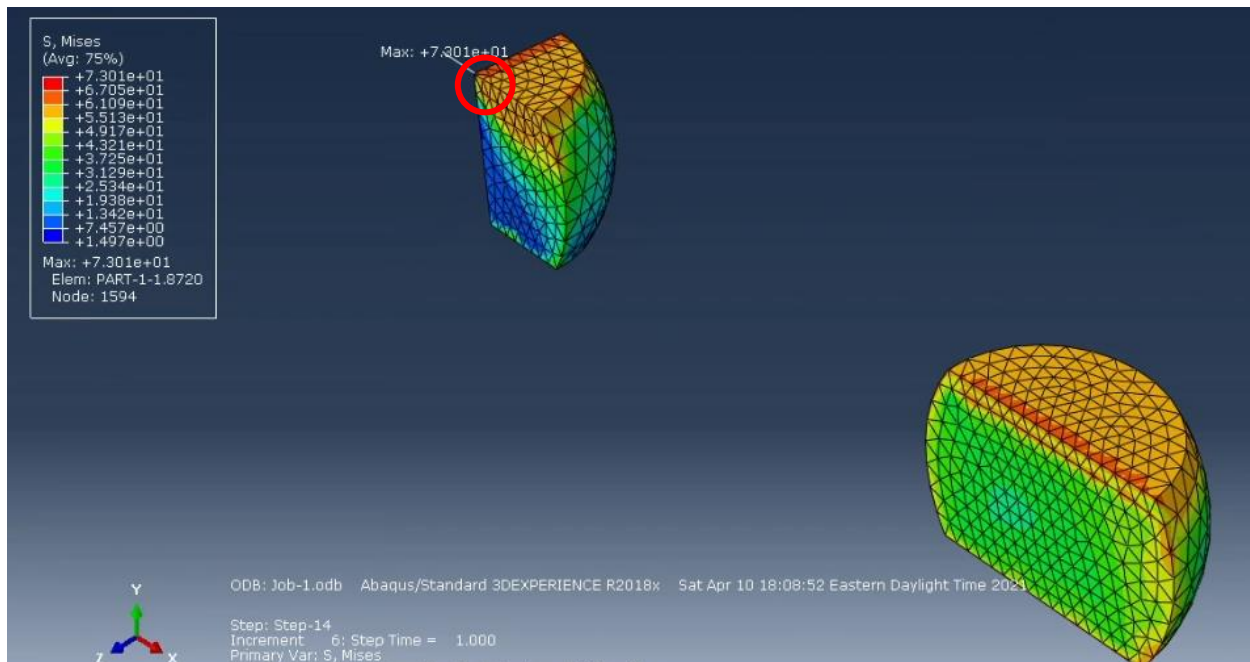


*Figure 9 Complete Filled Quarter Model Critical Location (Solder)*

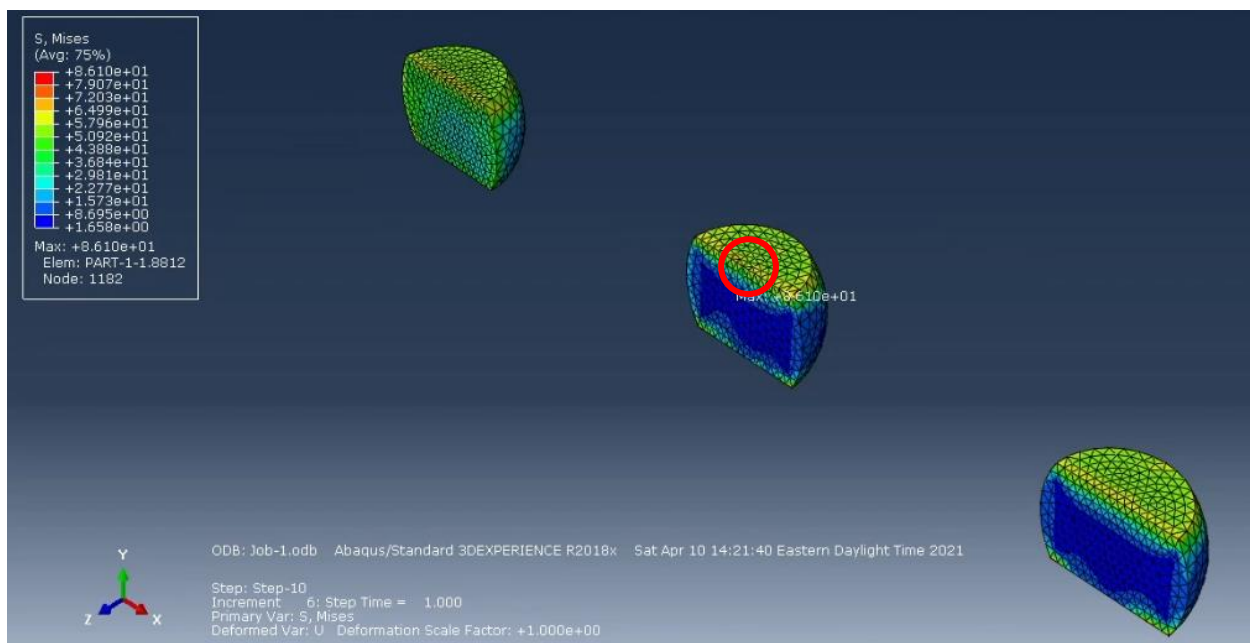Critical location for incompletely filled half model:



*Figure 10 Incompletely Filled Half Model Critical Location (Solder)*

Note in Figures 9 and 10, only the Solder is shown and the remaining components have been turned off but were still part of the analysis.

# Appendix:

Simulation Run Times:
Completely Filled Quarter Model ~ 52 mins

Submitted: Sat Apr 10 18:08:18 2021

Started:   Analysis Input File Processor

Completed: Analysis Input File Processor

Started:   Abaqus/Standard

Completed: Abaqus/Standard

Completed: Sat Apr 10 19:00:56 2021

Incompletely Filled Half Model ~ 92 mins

Submitted: Sat Apr 10 14:21:01 2021

Started:   Analysis Input File Processor

Completed: Analysis Input File Processor

Started:   Abaqus/Standard

Completed: Abaqus/Standard

Completed: Sat Apr 10 15:53:00 2021