Simulation of Internal Shorting of Lithium Ion Battery

Problem Statement

Internal shorting of lithium ion batteries is considered to be very dangerous. However, experimental study of such internal shorting is very challenging and expensive at the same time. By using AutoLion 3DTM, we demonstrate that the internal shorting of lithium ion battery cell can be simulated quickly and accurately. It is also shown that during internal short, cell surface temperature is substantially lower than temperature at shorting location. This suggests that the use of a thermocouple to gauge surface temperature rise as a “red flag” is ineffective.

Setup

- An 8Ah NCM/Graphite cell with stacked electrode design (SED) is set up in AutoLion 3DTM and the 3D cell mode is used. The internal shorting feature is enabled.
- The cell has a dimension of 70mm X 100mm in cross section and 6mm in thickness. The initial SOC of the cell is set to be 1.0.
- The 13th plate of the cell is internally shorted. The shorted area (1.3mm by 1.3mm) is located in the center of the cell. The short resistances used in the simulation are 500 mOhm and 2 Ohm, respectively.
- Convective heat transfer boundary condition (20 W/m²*K) is used for all the surface areas.

Results

Figure 1 shows the temperature contour of the shorted cell layer at 200 s. The shorting resistance is set to be 500 mOhm. It can be seen that the cell center where the internal shorting is located becomes very hot and the temperature there rises up to 530°C. The cell surface temperature, on the other hand, is very cool compared to the temperature at the short (Figure 3). The reason is that cell heating resulted from internal shorting is very much localized compared to external shorting (see other case studies discussing external short). In a very short time (almost instantly), the currents from all the cell plates pass through this shorted small area and generate large amount of heat, which results the extremely high temperature at the shorted location. However, in the cell thickness direction, the heat conductivity is very limited, which results in very large temperature gradient in this direction. So even when the temperature at shorted location rises above thermal runaway limit almost instantaneously, the temperature at the cell surface remains largely unaffected. This proves exactly the difficulty of detecting internal short just by measuring cell surface temperature.

Figure 2 shows the same temperature contour at the same time (200s) but the shorting resistance is set to be 2 Ohm. With increased short resistance, the shorting current is greatly reduced. Therefore, the heat generating at the short is also significantly lower compared to the 500mOhm case. It can be seen from Figure 2 that the heating is still very local but the absolute temperature at the short is about 170°C, which is much lower than the 500mOhm case. Large
difference between temperatures at shorted location and cell surface is still very obvious (Figure 4) for the same reason stated in the 500mOhm case.

Since cell heating from internal short is very local, it is worthwhile further investigating if internal shorting can be quickly detected by measuring the cell surface temperature. Figure 3 shows the temperature comparison of the 500mOhm case at the short and at the cell surface (averaged temperature) throughout the internal shorting process (0-200s). It can be seen that 1) the temperature at the short increased almost immediately above thermal runaway limit and then continued to increase slowly, and 2) the max temperature at the surface also increased but in a much slower rate. For example, between 0-50s, the surface temperature is only increased from 25°C to 45°C, which is much lower than the temperature at short. So in reality, it would be impossible to detect internal shorting of cell by just measuring the surface temperature in seconds, when temperature at short already reaches thermal runaway limit.

Figure 4 below shows the max surface temperature and the temperature at short for the internal shorted cell with short resistance of 2 Ohm. The same trend as the 500mOhm case is observed. The only difference is that the absolute values of temperatures of 2 Ohm case is much lower compared to the 500mOhm one but still very large difference between short location and cell surface temperatures is observed. In this case, it is still impossible to detect the internal shorting by gauging the cell surface temperature.

**Summary**

- Simulation performed in approximately two hours with standard computing resources. It is very fast considering the complicated physics behind internal short of cell.
- Experimental testing of internal shorting is very challenging, if not impossible and not repeatable. In contrast, AutoLion-3DTM provides a time and cost effective means to evaluate the impact of internal short on Lithium Ion cells and effectiveness of various mitigating strategies.
- Internal short is very tough to detect by conventional means such as thermocouple at cell surface. Basically in seconds the temperature at shorted location rises above thermal runaway limit while the cell surface temperature remains largely unaffected.
- AutoLion-3DTM can readily be used for rapid analysis of safety designs to prevent thermal runaway of large format Li-ion cells undergoing internal shorting. This unique capability is one of many reasons that AutoLion-3DTM easily stands out from all the other battery simulation softwares.
- Different sizes and types of cell chemistries, cell sizes, internal shorting locations, and shorting area sizes can readily be simulated using AutoLion-3DTM. In addition to all the thermal parameters such as temperature and heat source during pack safety simulation, electrical parameters such as voltages and currents can also be outputted by AutoLion-3DTM.