Thermal Design for Lithium Sulfur Batteries: The Effects of Welding Resistance

R. Purkayastha[1] *, S. Schleuter[*1], G.Minton[1], S. Walus[1] , M. Wild[1]
[1]OXIS Energy, E1 Culham Science Centre , Abingdon, OX14 3DB
*Corresponding author: OXIS Energy, E1 Culham Science Centre, Abingdon, OX14 3DB raj@oxisenergy.com

Abstract: As OXIS Energy begins to scale up production of Lithium Sulfur cells to pouch cells, thermal design becomes important. In this study a close look is taken at the weld between the tabs and the electrodes, to see if the resistance at this point also plays a role. An innovative coupon design was used in order to obtain results which were then experimentally validated. It was found that the values of these resistances are low in comparison to the actual tab resistance, but this will change when wider and/or thicker tabs are used, due to the Joule heating present in the tabs themselves. It was also found that the resistance would have to be increased by two orders of magnitude in order to have a noticeable impact, which potentially means this is a term which can be neglected in overall heat modelling of the cell.

Keywords: Lithium Sulfur, Pouch cells, welding design

1. Introduction

The Revolutionary Electric Vehicle Battery (REVB) project was set up to develop and test a cell that would be suitable for automotive purposes. A higher capacity cell would involve the use of higher currents, which leads to increased joule heating effects at the tabs and welds. Moreover, the geometry of the cell means that more heat is generated within the cell, and given the nature of packing into a battery pack, all of this heat flows though the thin tabs. Hence it becomes important to investigate the entire tab and weld structure, in order to optimise heat flow and minimise lossy effects such as joule heating

1.1. Description of Tab welds

The Lithium Sulfur cell consists of a cathode with sulfur which is coated onto an Aluminiium current collector. The anode consists of lithium metal foils. The cell is constructed in a layered manner with alternating layers of cathodes, separators and anodes. The current collector edges are welded to an aluminium tab through which current is passed. Similarly, the lithium anodes are welded together to a Nickel tab. The goal of this study is to look at joule heating developed as a result of weld resistance between the electrodes and the tabs, as well as the joule heating within the tab itself

1.2. Experimental setup and values

A special coupon was designed as shown in figure 1.

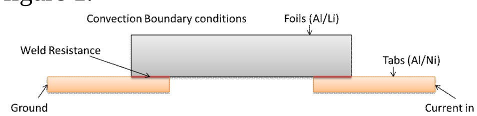


Figure 1. Set up of model as well as experiment.

20 mm wide strips of material that form the current collector (aluminium foils) and the anode (lithium metal) were cut and stacked to different heights. They were then welded to the respective tabs (aluminium foils to aluminium tab and lithium foils to nickel tab) on either side. This creates a symmetrical design that is not only easy to measure experimentally, but also easy to reduce down to a 2-D model. In the experimental set-up current was passed through the tabs and the change in temperature was measured using a thermal camera. The benefit of this system is that no electrochemical cells are required and therefore high temperatures can be recreated, which would ordinarily cause safety concerns.

2. Description of Model in COMSOL Multiphysics®

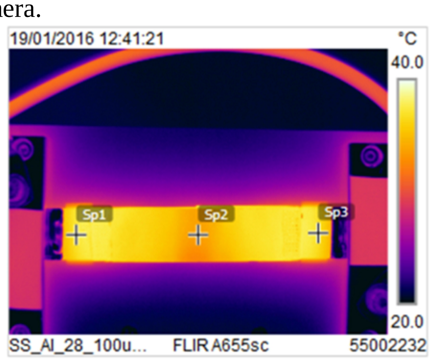
COMSOL 5.2 was used for these models. The effect of heating due to current was modelled using COMSOL's inbuilt Joule Heating module. This module couples the Electric Currents module with the Heat Transfer module in order to give the combined effect of heat flow and electric currents.

The foils and tab materials are modelled as solids with values of specific heat capacity, density and thermal conductivity taken from the COMSOL materials library. The electrical resistivity of the aluminium tab is 2.3e-08 ohm-m and 5e-08 ohm-m for the nickel tab. The electrical boundary conditions were current in at one end of the tab material, and ground at the end of the opposite tab. The other surfaces are electrically insulated . The thermal boundary conditions were convection on the entire surface. The convection coefficients were fitted from experiments. For Al-Al this is 15 W/m^2-K and for the Ni-Li system this is 10 W/m^2-K. A weld resistance is inputted as a surface impedance across the tab – foil interface, depicted in the schematic in figure 1 by the red lines. The initial temperature is set at 19 °C, and this value is used as the ambient temperature for the convection calculations as well. The value of the aluminium-aluminium weld resistance is 30 µohm and the value for the lithium-nickel weld is 136 µohm. The aluminium foil stack is 0.36 mm in height and the lithium foil stack is 5 mm in height.

A two-dimensional model is used to model the weld coupons as seen in figure 1. A comparison was made with three-dimensional models and there is not difference to the results. This is because the only parameter that can be possibly affected is the heat loss due to convection, and the surface areas accounted for in the three dimensional case are too small to account for major changes.

3. Validation : Al-Al samples

We first validate the model with images takes of the special coupon set up with the thermal camera.



Measurements	°C
Sp1	37.2
Sp2	34.0
Sp3	37.0

Figure 2(a) : Image from thermal camera setup. Al-Al weld coupon system with Al tabs 0.1 mm thick. The current passed is 50 A and time of measurement for both is 5 mins.

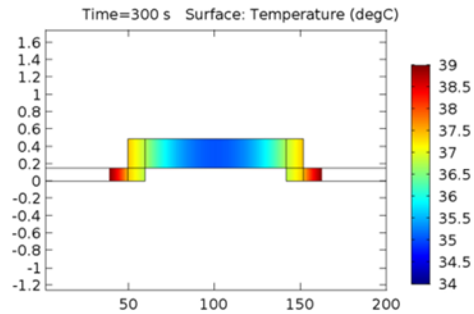


Figure2(b) : Image from Simulation

For 50 A flowing though the metal coupon the temperature gradient across the region of interest is around 5 degrees. The region under the weld is the hottest part of the foil, and the value in the simulation matches the experiment quite well. In the experiment, the rest of the tab was placed under the copper block and therefore its temperature cannot be seen. However in the simulation we assume it is all exposed to air rather than sitting under copper. An issue with this is that the native joule heating within this tab region leads to a temperature rise in the tab region not seen in the experiment. More interestingly, as will be described in a later section, it can be the hottest part of the coupon. The point Sp2 corresponds to the centre of the foil, while Sp1 and Sp3 correspond to the weld region. Comparing data we get the following plot (figure 3).

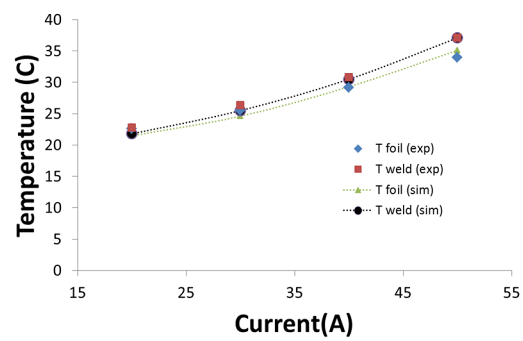


Figure 3: Comparison of experimental and simulation data for current passed through an Al-Al weld coupon setup. The Al tabs are 0.1 mm thick and the current is passed for at least 5 mins.

The values match well; experiments were only done until 50 A but the simulations have been extended to 100 A, which for a 20 Ah cell would be a 5C rate.

4. Tab weld predictions : Ni-Li and thicker tabs

After validating the model, we move onto the Li-Ni system, as well as a system with thicker tabs.

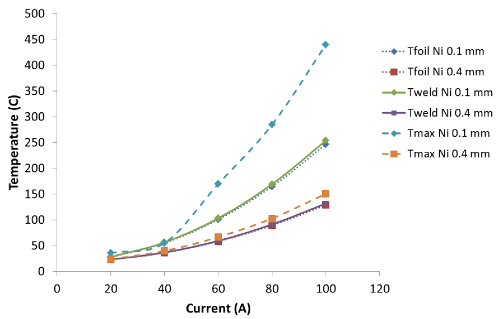


Figure 4 : Temperature as a function of different currents across Ni-Li coupon system . Current is passed for at least 5 mins. Ni tabs are 0.1 mm and 0.4 mm thick.

The Ni-Li system shows much higher temperatures than the Al-Al system. This is due to the higher native resistivity of the Nickel as well as the increased thickness of the lithium foils. 'T_{foil}' refers to the temperature at the centre of the foil, 'T_{weld}' refers to the temperature at the interface between the tab and the foil, and 'T_{max}' refers to the maximum value of temperature across the entire system. Overall, the values for the system with the thinner tabs are higher than the thicker tabs. The location of the maximum value of the temperature for this system is at the ends of the tab. In the actual experiment, due to the presence of copper blocks over most of the tab, we cannot identify the temperature at those points. The foils do not have much of a temperature gradient across them, as the values of T_{weld} and T_{foil} for both sets of thickness are relatively close to each other.

The Al-Al system shows similar behavior and we do not go into too many details. However, for the case of 0.4 mm thick tabs, the size of the foil stack becomes quite similar to that of the tabs. Thus for this system, the maximum temperature does not occur at the tab ends, but in the middle of the foils. As predicted in the earlier section, if the overall resistance of the tabs decrease to a value below that of the weld resistance and foils, the area of temperature rise will shift away from there onto the weld and foil regions. The effects can be seen in figure 5.

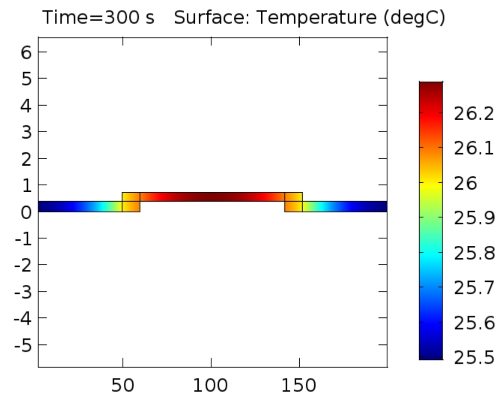


Figure 5 : Temperature gradient across the Al system with Al tabs = 0.4 mm at 300 s when 40 A is passed through it. Figures are rescaled in the y direction

6. Weld resistance modifications: Effect on temperature and current distribution

Until now we've been using one value of weld resistance. However, this value is likely to change if thicker tabs are used. More importantly, a 'bad' weld with higher interfacial resistance will lead to large temperature rises.

For both Al-Al system and the Ni-Li system, the 40 A case was chosen, which correlates to a 2C discharge for a 20 Ah cell. Four cases were tried, the base case with the experimentally derived values, the ideal case with no resistance, one case with the value of resistance an order of magnitude lower than the measured value, and the final case with the value of resistance an order of magnitude higher than measured experimentally.

6.1 Al-Al system

In figure 6 the temperature profiles of two cases are considered : (a) the base case (b) ten times higher weld resistance. For cases (a) maximal temperature occurs at the tabs. This shows that the current resistance as measured is low enough to be neglected, as it does not contribute significantly to the heating. For the case with the resistance an order of magnitude higher, figure 6(c), the maximal temperature occurs in the weld region, giving us some indication of what values are required in order to see a noticeable temperature rise in that region.

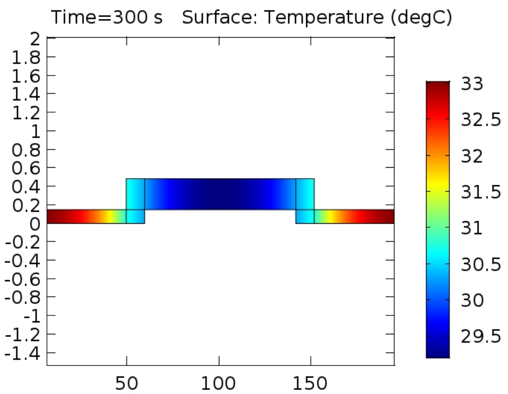


Figure 6 (a) : Temperature for the base case setup Al-Al coupon system

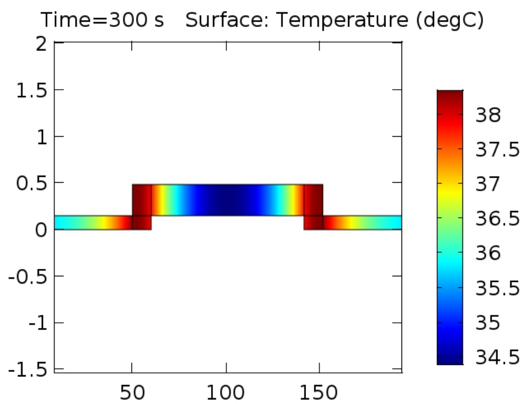


Figure 6(b) : Temperature for the case where the weld resistance is 10 times the base setup Al-Al coupon system For both cases the temperature is at 300 s after 40 A of current is passed through the system. Figures are rescaled in the y direction

The current densities in the x-direction are similar and we do not show them here. In Figure 7 the current direction in the y direction is seen. Figures 18 and 19 show the current densities in the x and y direction respectively for the case with higher resistance and the base case. The main current flow is in the x direction and the magnitudes are the same in both cases. The current distribution in the y direction is more interesting. The base case shows a higher value of current density, but it is not evenly spread, with a larger value towards the free edge/leading edge of the bend between the tab and the foil. For the case with the higher resistance, the value is lower, but more evenly spread. The distribution can be correlated with the temperature rise, which given that its magnitude is determined by the x component, he heating is proportional to I^2R. Thus on increasing the weld resistance you increase the heat generated there.

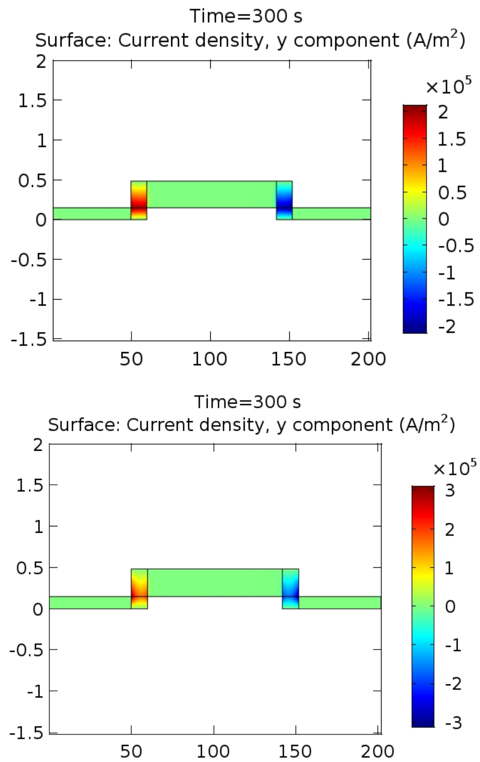


Figure 7 (a) : Current density in the y direction for the setup case where the weld resistance is set to ten times higher than the base case setup Al-Al coupon system (b) Temperature for base case setup. For both cases the temperature is at 300 s after 40 A of current is passed through the system. Figures are rescaled in the y direction

6.2 Ni-Li system

Compared to Al the joule heating for the lithium nickel system is significant, with temperatures rising up to 85 C. In figure 8 (b) the case with weld resistances increased by an order of magnitude is shown. The maximal temperature for this system is around 103 C at the weld area, which is significant.

In figure 9 the current density in the y direction is shown for the case of higher resistance (a) and the base case (b). Similar to the Al-Al system, the distribution of the current densities is linked with the temperature distribution, and we abstain from any further commentary.

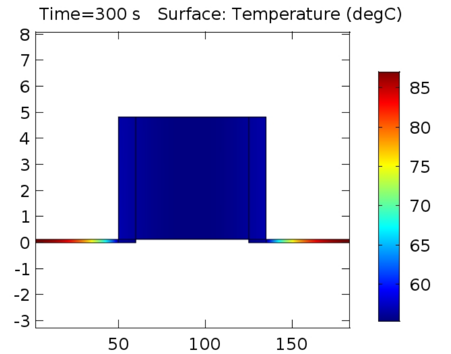


Figure 8 (a) : Temperature for the base case setup Ni-Li coupon system

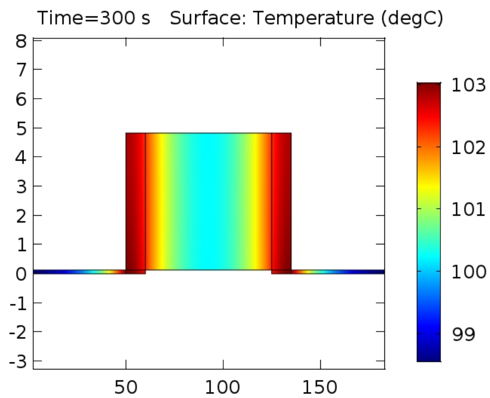


Figure 8 (b) : Temperature for the case where the weld resistance is 10 times the base setup Ni-Li coupon system (For both cases the temperature is at 300 s after 40 A of current is passed through the system. Figures are rescaled in the y direction

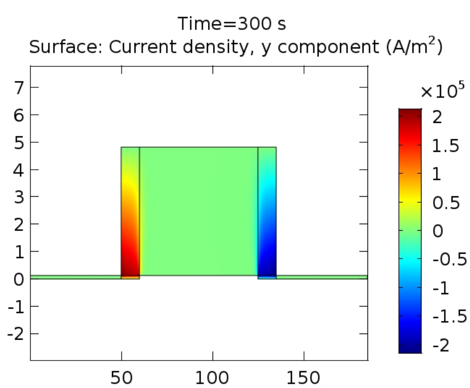


Figure 9 (a) : Current density in the y direction for the setup case where the weld resistance is set to ten times higher than the base case setup Ni-Li coupon system

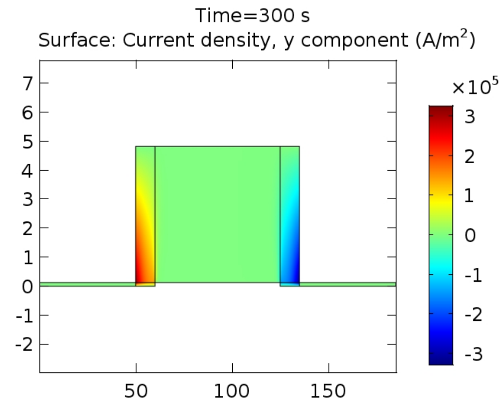


Figure 9 (b) Current density for base case setup. For both cases the temperature is at 300 s after 40 A of current is passed through the system. Figures are rescaled in the y direction

7. Redistributing the resistance: Ni-Li

In all of the simulations the placement of the resistance is idealised, in that it is present only at the interface between the nickel tab and the lithium foils. However, the measured resistance is likely to be distributed amongst the layers of the foils themselves. A simple test was carried out wherein the resistance was split into two : the first resistance was place at the interface of the nickel and lithium and the second resistance was placed within the lithium foils, at a height of 10% of the total from the nickel tab.

In figure 10, the setup has the experimentally measured resistance, with (a) showing the temperature distribution where 90% of the resistance is at the nickel tab interface with the remainder in the foils. In (b) only 10% of the resistance is at the nickel lithium interface with 90% between the foils. As can be seen the temperature difference is marginal. This is because in this case, the main source of heat comes from the joule heating in the nickel tab rather than the weld resistance itself.

If the weld resistance is increased by an order of magnitude more interesting results emerge. In figure 11(a) 90% of this higher value of resistance is at the nickel lithium interface and 10% between the foils. Compare with the results in figure 8(b). The temperature has already reduced from a peak of 101 ^{0}C to 97 °C. When we reduce the resistance even further to 10% at the interface, then it flips back to the case of the experimentally measured resistance. This is because while current has to flow through the nickel lithium interface, it need not flow upwards, in the y direction, through all the lithium foils, prior to flowing in the x direction. Thus by shifting the resistance to just 10% above, we have provided a sufficiently conductive pathway that electric current need not flow through the resistance there, thereby not contributing any joule heat to the system. Thus in this particular experimental setup, it is possible to have a situation wherein current might not be flowing through all the foils. This would not occur in an actual cell since the presence of electrochemical reactions at each of the foils provides a source of current.

However, what this also proves, is that the weld resistance has maximum impact in this situation at the nickel lithium interface in terms of contributions to joule heating.

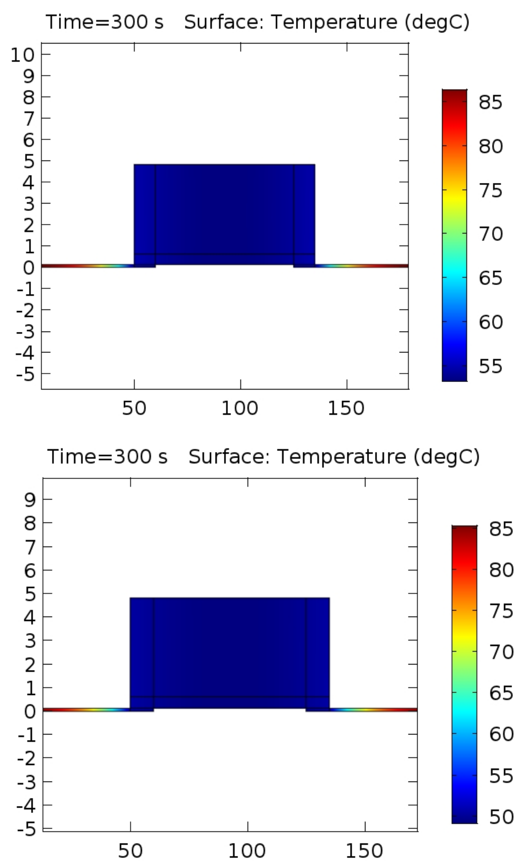


Figure 10: Ni-Li systems with 0.1 mm thick Ni tabs. Figures are rescaled in the y direction. The total weld resistance is the same as the experimentally measured value. (a) The weld resistance is redistributed with 90% at the Li-Ni interface and 10% at a height of 10% of the total height.(b) The weld resistance is redistributed with 10% at the Li-Ni interface and 90% at 10% height above the Nickel tabs

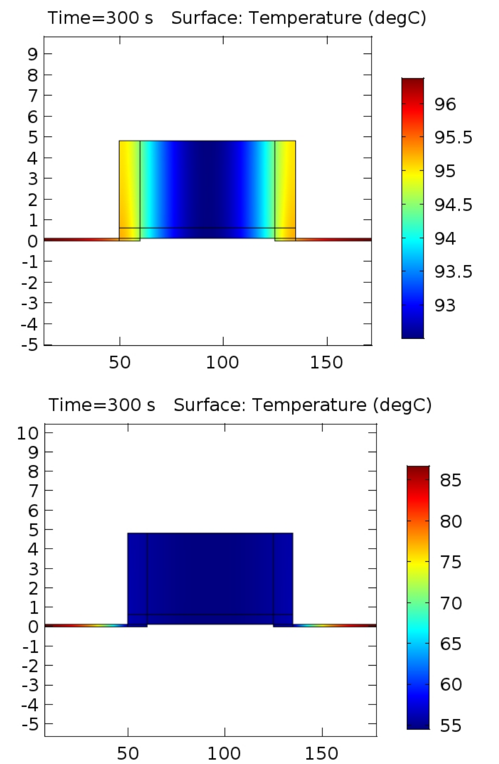


Figure 11: Ni-Li systems with 0.1 mm thick Ni tabs with 47 lithium foils which are 100 µm thick. Figures are rescaled in the y direction. The total weld resistance is ten times higher than the experimentally measured value.(a) The weld resistance is redistributed with 90% at the Li-Ni interface and 10% is kept at a height of 10% of the total height (b) The weld resistance is redistributed with 10% at the Li-Ni interface and 90% at a height of 10% of the total height.

8. Conclusions

A study into the effect of joule heating at the weld interface between metal foils and tabs was presented. Weld resistance contributes to joule heating significantly only when its value is quite large, and/or comparable to the resistance of the tab itself. Otherwise the joule heating within the tab is the main source of heat. This result is interesting for a number of reasons. Large temperature rises around the weld can be a quality indication of a bad weld, with poor connections. Secondly, for thermal cooling designs for electrochemical cells which involve pulling heat out through the tabs via the busbars, the generation of joule heating would create an adverse thermal gradient and not allow heat to flow out of the cell. This is something that should be taken into consideration when designing such a system.

9. Acknowledgements

All the authors would like to thank Innovate UK for co-funding this work via the Revolutionary Electric Vehicle Battery (REVB) project (Project Number: 101573).