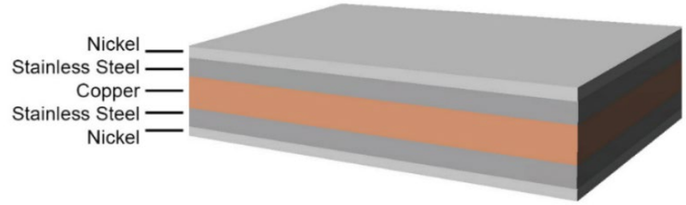
SigmaClad®



High conductivity CLAD Metal Battery Cell Connectors (SigmaClad®) That Reduce Temperature, Improve Pack Safety & Reliability, & Are Easily Welded and Soldered.

Abstract

Lithium-ion battery packs utilize individual cells that are connected in series and parallel arrangements to produce the desired capacity (amp-hours) and voltage for the battery pack application. These connections are made using an appropriate cell connector that considers the following criteria:

1. Electrical and thermal conductivity (minimize pack temperature during worst case conditions- joule heating).
2. Cell Weldability (resistance, laser, etc.)
3. Solderability (for battery management system voltage measurement connections)
4. Corrosion resistance

A good cell connector material system should minimize temperature rise, reduce thermal gradients, and help minimize a pack's overall resistance, to maximize power to the end application (load). In addition, the cell connector needs to be weldable and solderable for ease of manufacturing.

Thermal modeling (CFD) and actual testing will demonstrate the benefits of using SigmaClad® versus competing materials. In addition, soldering and welding considerations will be discussed.

Introduction

Clad metals are a great solution when a mono metal cannot obtain all the desired results. In the case of cell connectors, clad metals offer some unique advantages that will be discussed in this paper.

Engineered Materials Solutions (EMS) has developed SigmaClad®, a unique five-layer cell connector material system in which each layer performs a certain function that would not be obtainable with just one material.

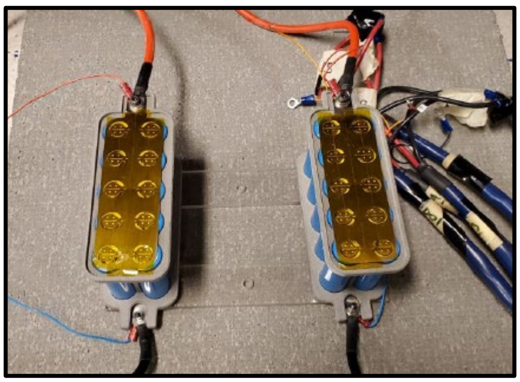
The material system looks, forms, stamps and processes like a mono metal while offering unique electrical, thermal and manufacturing advantages. The outer nickel layers promote solderability, the inner stainless-steel layers provide mechanical toughness and weldability, and the inner copper layer enhances electrical conductivity and thermal performance.

This paper will compare packs made with SigmaClad and packs made with nickel to show both temperature and reliability improvements.

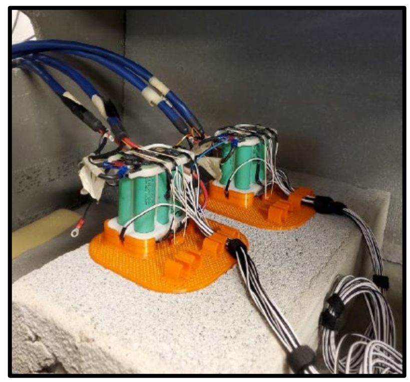
Initial pack temperature comparisons are best demonstrated using thermal modeling (CFD); however, the initial model must be validated to ensure model assumptions are correct.

This paper will evaluate a 1s10p battery pack utilizing Samsung INR21700-50E cells. Packs will be made and modeled using 0.25 mm cell connectors made from SigmaClad® and Nickel for both temperature comparison and model confirmation. Both theoretical modeling and actual testing show the temperature improvements utilizing SigmaClad®.

In addition, actual capacity fade testing was conducted on a 1s6p pack utilizing Samsung INR18650-25R cells. Packs were made once again with 0.25 mm nickel and 0.25 mm Clad metal and tested side by side to show improvements in pack reliability when using Clad metal cell connectors (SigmaClad®).



1s10p 21700 pack



1s6p 18650 packs

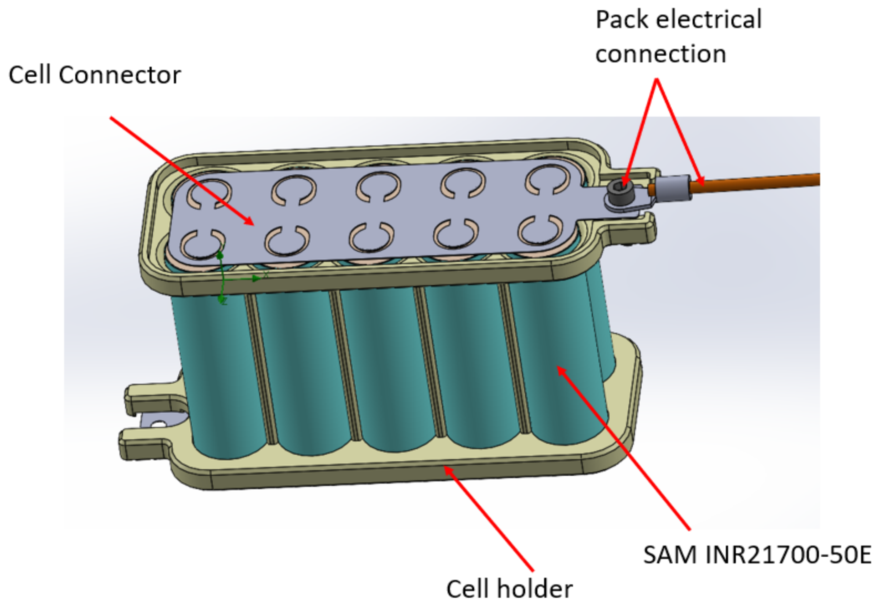
Thermal Modeling (CFD)

Computational Fluid Dynamics (CFD) with joule heating is utilized to predict pack temperature (both transient and steady state).

For a thermal model to be accurate, two separate heat sources must be considered: 1. The cells' thermal behavior and 2. joule heating of the cell connector. In addition, appropriate heat loss must be considered (conduction, convection, and radiation).

A simplified cell model was used and assumed 1W heat generation. This was based on a 1C discharge and includes both irreversible and reversible heat generation for the cell. It is understood that the cells internal resistance is a function of SOC (state of charge), however this simplified model provides accuracy within the requirements of this analysis.

CFD Solid Model of 1s10p battery pack



CFD Material Properties

Component	Material	Density (Kg/m^3)	Specific Heat ($J/Kg\text{-}^oC$)	Conduction Coefficient (W/m-k)	Electrical Resistivity (Ohm-m)
Cell Cap & Case	Steel	7870	472	51.9	1.74 x 10-7
Cell Core	Insulator	2000	900	Kx=Kz=1.6 Ky=3	insulator

Component	Material	Density (Kg/m^3)	Specific Heat ($J/Kg\text{-}^oC$) @ 20^oC	Conduction Coefficient (W/m-k) @ 20^oC	Electrical Resistivity (Ohm-m) @ 20^oC
Electrical connection components	Copper	8960	384	400	1.74×10^{-8}
Cell Connector 1	Nickel	8900	456	79	8.500×10^{-8}
Cell Connector 2	SigmaClad(R)60	8580	423	253	2.856×10^{-8}
Cell holder	Nylon-66	1150	2200	0.27	insulator
Cells	See table above				

Note: Electrical resistivity and thermal conduction properties varied with temperature (temperature dependent data not shown).

Heat Generation:

1W injected at the bottom of each cell

4.9A injected at the top of each cell with zero potential defined at the end of the copper wire.

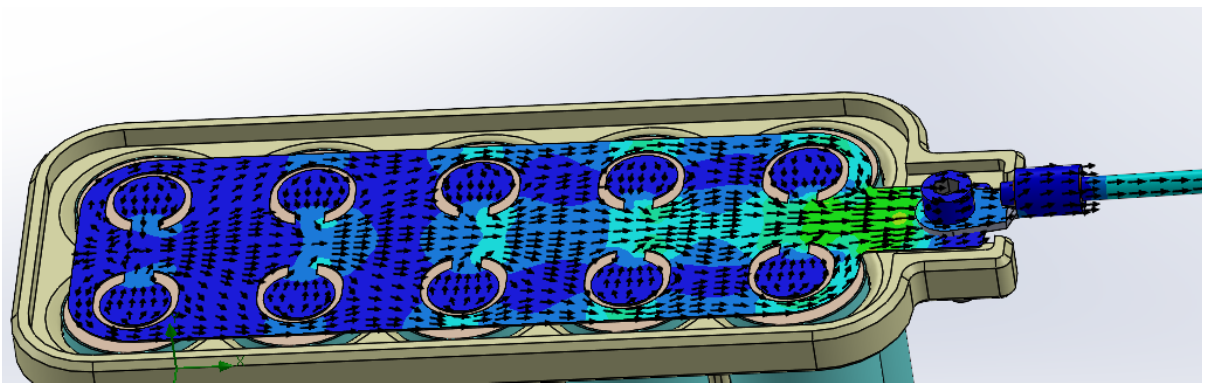
Heat loss assumptions:

Conduction – as defined by each material property

Convection – natural convection in the direction of gravity

Radiation (cell connector) – black body wall (Nickel Emissivity of 0.35 at 300K)

Ambient Temperature 20ºC

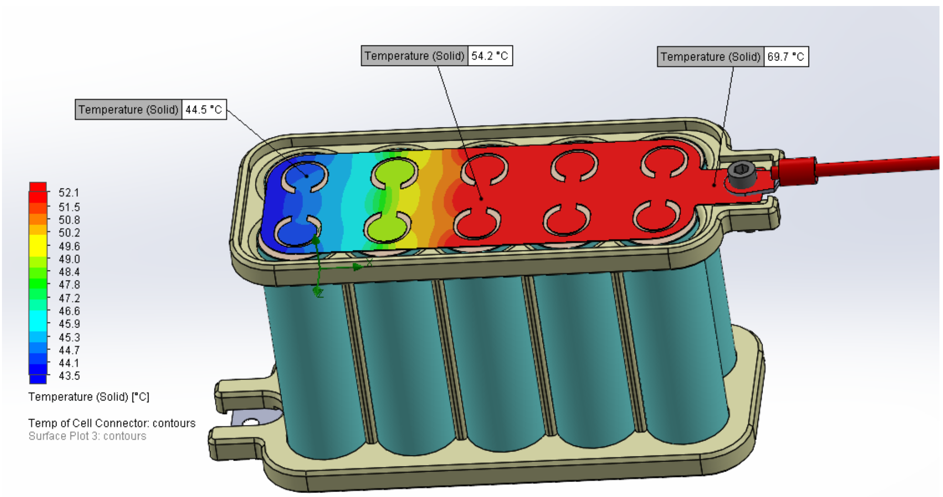


Current density plot

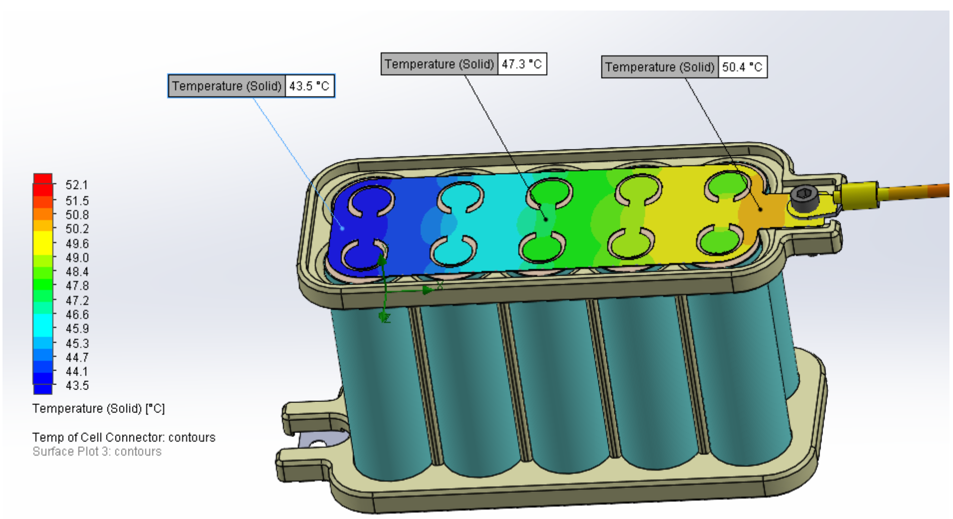
Results (predicted)

The following are CFD thermal model results and actual IR test results for the packs made with Nickel cell connectors and the pack made with SigmaClad®60 cell connectors for a 1C discharge.

Nickel Cell Connector (1C discharge) 49A for 1 hour

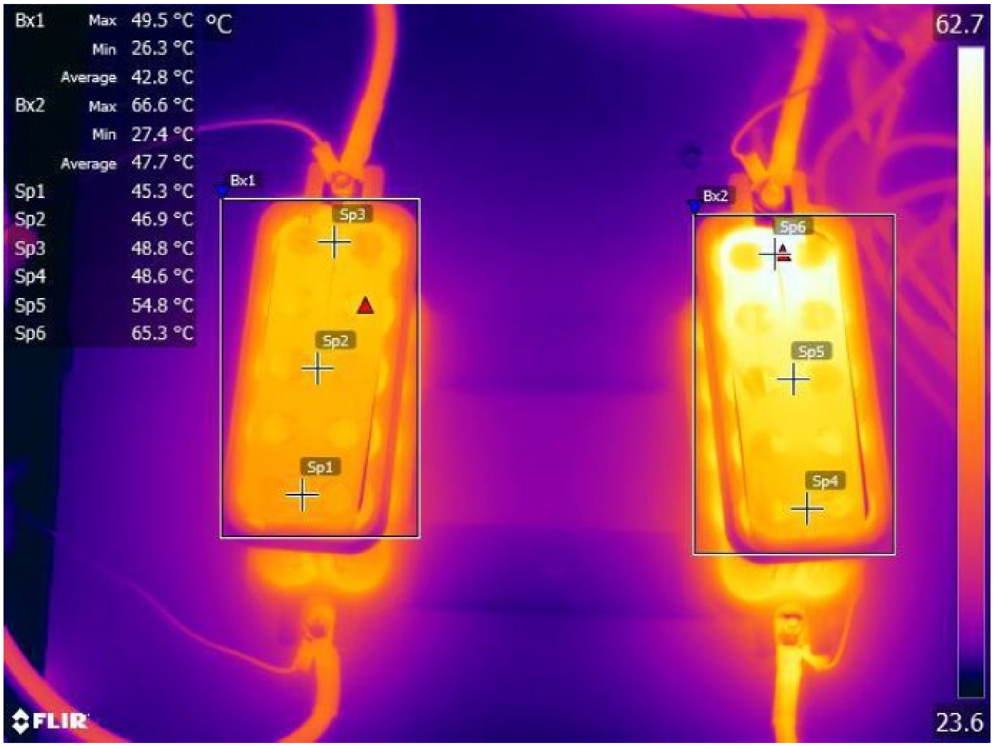


SigmaClad®60 Cell Connector (1C discharge) 49A for 1 hour



Results (Actual)

Image taken 1 hour of continuous 49A discharge



SigmaClad® **Nickel**

Based on thermal model results as well as actual testing, the battery pack made using the SigmaClad cell connector runs cooler and has less temperature gradient. The battery pack made with a nickel cell connector has a 34% temperature increase over SigmaClad® and a much greater temperature gradient across the connector.

	Max Temperature		Temperature Gradient	
Cell Connector	**Model**	***Actual***	**Model**	***Actual***
Nickel	69.7	***65.3***	25.2	***16.7***
SigmaClad®60	50.4	***48.8***	6.9	***3.5***

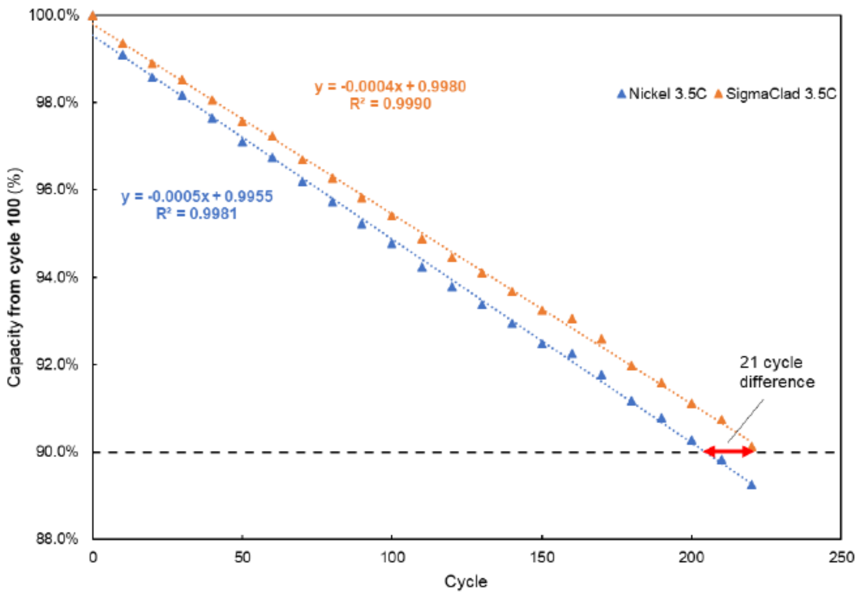
Note: Data in the table used to describe pack performance improvement is from actual testing (model data shown only for comparison). This is a very significant difference in temperature and temperature gradient which will result in improved pack reliability and safety.

Capacity fade testing (1s6p battery pack)

Capacity testing was not modeled but was characterized by doing actual testing. Packs made with 0.25 mm nickel and 0.25 mm SigmaClad® cell connectors were tested side by side.

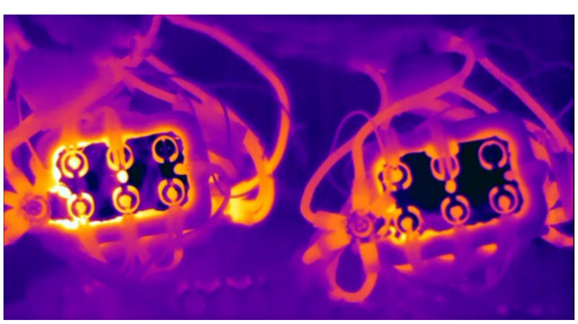
Packs were charged at 1C (15A), rested for 1 hour, discharged at 3.5C(52.5A), and rested for 1 hour.

The test was stopped at 90 % S.O.H. (State of Health).



This data shows that it takes twenty-one additional charge/discharge cycles for the battery pack made using the SigmaClad® cell connector to reach 90% S.O.H. than the packs made with nickel. This is a 10% improvement

IR image of 1s6p packs during capacity fade discharge cycle



Nickel **SigmaClad®**

Cell connector design consideration for individual cell fusing

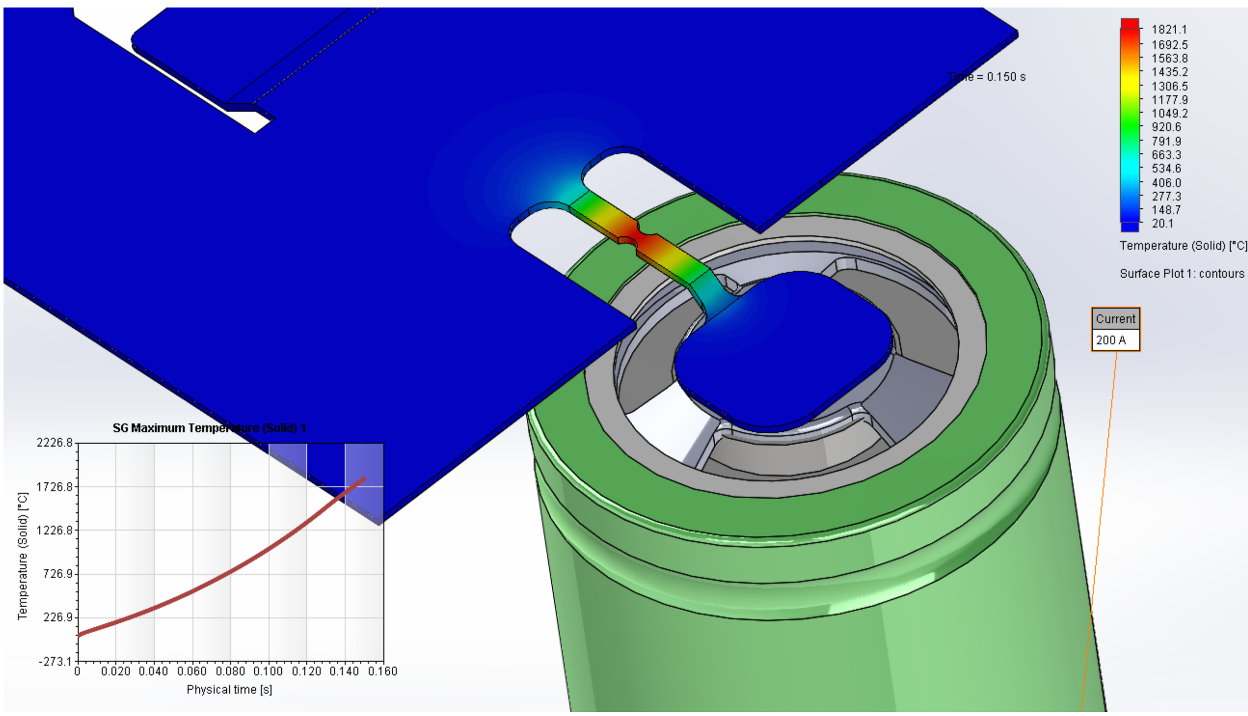
Cell connectors can be designed with features that can act as a fusible link during high current events.

Thermal modeling should be considered to assist in the initial determination of the fuse geometry suitable for both normal operation and fuse open events.

SigmaClad® material properties are well understood so that accurate thermal modeling can be completed to determine the appropriate fuse open current and time.

It can be assumed that the SigmaClad® will fuse open between the temperatures of 1,000°C and 1,400°C (approximate melting range).

The CFD joule heating transient temperature analysis results shown below is an example of an initial fuse geometry study. In this case, the fuse link will open after 150 milli-seconds when exposed to 200A.



Actual testing with prototype parts is the final step required to ensure the fuse tab meets all design requirements. Engineered Materials Solutions can assist with both modeling and physical testing if required.

Pack manufacturability using Clad metal

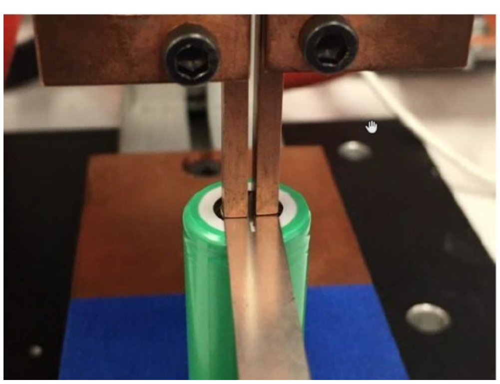
As described earlier, the copper center layer of SigmaClad® provides enhanced electrical and thermal conductivity which makes it a superior cell connecting material. The exterior stainless steel and nickel layer of SigmaClad®'s five-layer system enhances and ensures it is easy to manufacture.

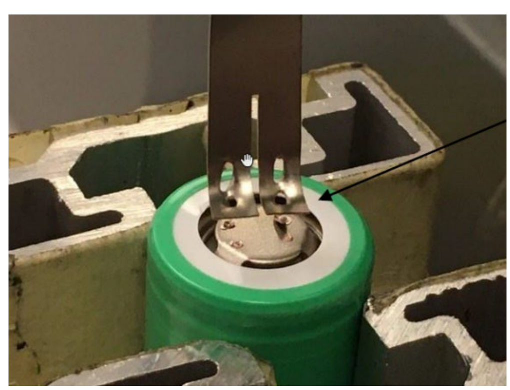
The outer nickel layers provide a solderable surface to connect to the BMS (Battery Management System) for voltage measurements. This is a required connection when measuring cells in series to ensure that the individual cells are not exposed to over or under charge conditions. In addition, the nickel layers offer enhanced corrosion protection.

The stainless-steel layers provide mechanical strength and a surface that is excellent for resistance welding. We have worked in collaboration with Amada Weld Tech to establish weld parameters for the various SigmaClad® materials (see chart below). EMS provides cell connector design support to ensure that the cell connector geometry is optimized for resistance welding.

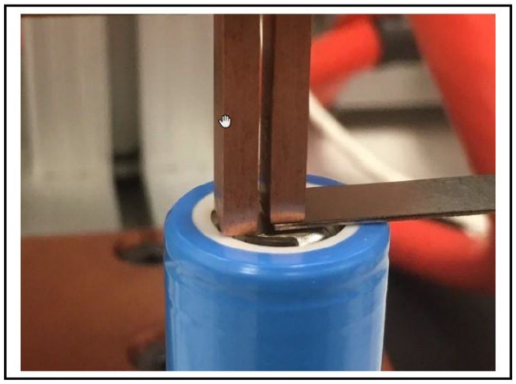
There are two types of resistance welding options that can be used to join the cell connector to the cell.

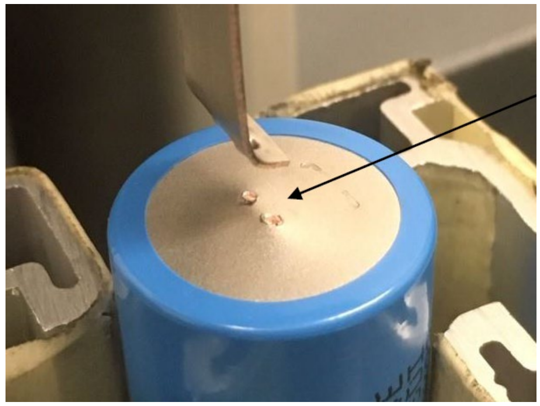
1. Parallel weld geometry: Parallel weld geometry is when both welding electrodes contact the cell connector which is on top of the cell. This geometry allows for two points of contact and typically makes four spot welds at one time. It is recommended that a shunt slot be designed into the cell connecting area where the welding takes place to minimize current leakage through the cell connector. In addition, weld projections are recommended to concentrate the weld energy at the desired locations.





2. Step weld geometry: A step weld is when one electrode contacts the cell connector and the other contacts the cell. This configuration requires a window in the cell connector to allow for one of the electrodes to contact the cell. A step weld will direct all the weld energy through the cell connector and directly to the cell (no leakage losses in welding energy). In this configuration, only weld projections are recommended.

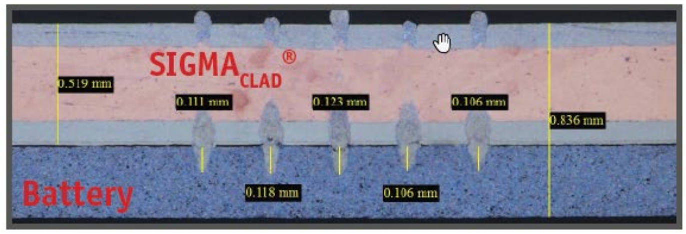




Material & Thickness	Electrode Config.	Anti-Shunt Slots? / Projections?	Weld Energy	Pull Strength (Kgs) Cathode/ Anode
SIGMACLAD® 40 0.127 mm	parallel	Yes/No	65	5.4/6.4
SIGMACLAD® 40 0.250 mm	parallel	Yes/Yes	150	23/28
SIGMACLAD® 40 0.400 mm	parallel	Yes/Yes	250	30/20
SIGMACLAD® 60 0.381 mm	parallel	Yes/Yes	275	23/31
SIGMACLAD® 60 0.508 mm	parallel	Yes/Yes	500	48/35
SIGMACLAD® 60 0.508 mm	step	No/Yes	150	38/38

Laser Welding is also possible using SigmaClad®. This technique is usually used when a single plane cell pack is desired, and it is necessary to weld the negative connection to the rim of the cell case. EMS has been successful in welding different SigmaClad® material systems to both the cell rim (negative) and cell button (positive) using laser welding. It is important to select the correct laser welding equipment and settings to ensure a good weld is made without compromising the cells integrity (typically 1/3 penetration). EMS can provide additional laser welding guidelines as required.

21700 Cell Laser Welded



Laser Welded Cross Section

Conclusion

The correct cell connector material can really make a difference in battery pack performance. Through both thermal modeling and actual testing, it was clear that SigmaClad® cell connectors showed a significant temperature reduction as compared to the competing nickel cell connector. This was due to the higher electrical conductivity. In addition, the thermal gradient was much more uniform when using SigmaClad® due to the higher thermal conductivity.

The other benefit of low electrical conductivity is to minimize the voltage drop at the terminals. The lower the voltage drop, the more available power at the terminals. This can be significant, especially when the electrical load being powered has a very low resistance.

It was also shown that running a pack at lower and more uniform temperatures improves the reliability of the pack. There was a 10% capacity fade improvement with packs made with SigmaClad® at only 90% SOH.

Lastly, the ease of solderability and weldability are significant attributes when choosing the right cell connector material. Long electrode life coupled with high quality, and repeatable welds will help with manufacturing productivity, yields, and battery pack reliability. In addition, SigmaClad® cell connectors can be designed with a fusible link geometry so that each cell is protected from undesired overcurrent events.