Addressing New Challenges in Laser and Resistance Welding for Battery Pack Assembly

INTRODUCTION

Battery pack assembly is a critical process in manufacturing today, particularly as applications in the electric vehicle (EV), consumer electronics, and power tools energy storage industries demand increasingly robust and efficient connections. To meet these demands, manufacturers rely on advanced welding techniques – usually resistance welding or laser welding - to ensure the durability, reliability and performance of finished battery packs. As battery module/pack design advances to address the need for better efficiency, higher storage, and faster charge/discharge properties, new challenges arise for the welding process used to make them. Resistance and laser welding each provide unique advantages to address these challenges.

This whitepaper aims to provide manufacturing engineers with a detailed understanding of how laser and resistance welding work and can be effectively applied in the assembly of cylindrical cell battery packs. We will explore five modern manufacturing challenges, and the key considerations for selecting a technology.

RESISTANCE AND LASER WELDING: THE FUNDAMENTALS

Before attempting to understand how these technologies are suitable for new welding challenges, it is important to know how they work.

Resistance welding uses electrical current to provide energy to melt and join two parts together: electrodes provide a mechanical force to bring and hold them in contact. The resistance between the materials and in the bulk induce heat that eventually exceeds the melting points, allowing the bond to form. When joining battery tab material to battery cans, the electrode configuration is as shown in Fig. 1a.

Laser welding - by contrast - is a non-contact welding method that works by irradiating parts with a high-energy beam of photons. The beam is absorbed by the material which heats the parts to the melting point allowing the materials to mix, creating a fusion bond upon cooling. Specialized tooling is required to hold the parts in intimate contact. Fig. 1b shows a laser welding schematic.

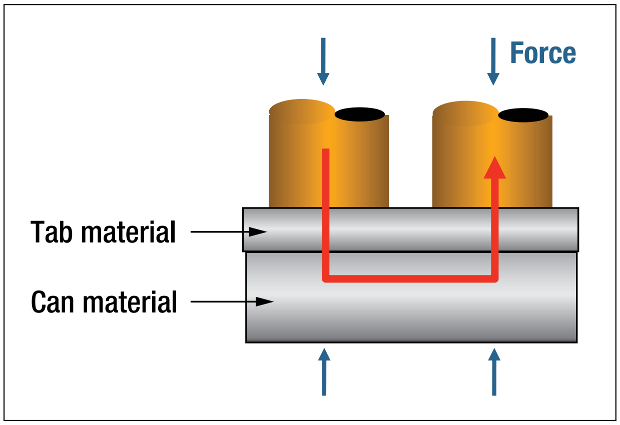

Fig. 1a - Resistance welding principle. Parallel electrode configuration.

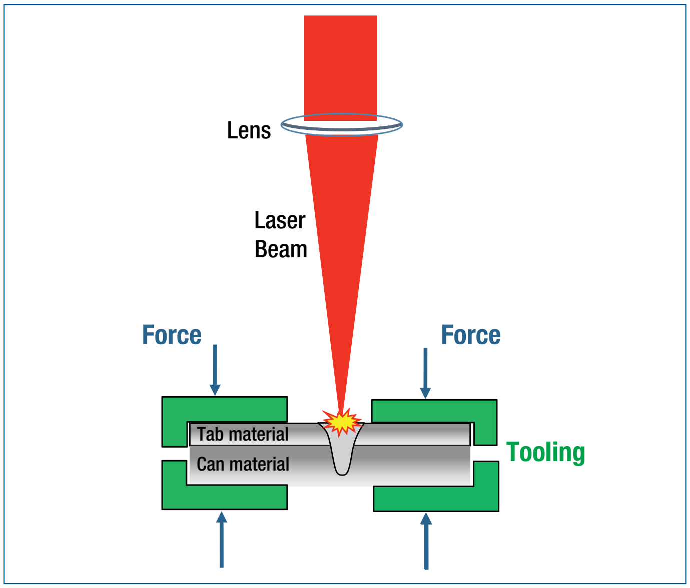

Fig. 1b - Laser welding principle

BATTERY PACK WELDING CHALLENGES

We recognize that there are numerous battery types and designs - each posing different challenges. To keep the text and length clear, this paper will focus specifically on joining tab material to cylindrical cells and the manufacturing challenges presented by newly designed battery modules/packs made with these cells.

While every application is unique, the modern battery pack assembly process poses several common challenges in the attempt to make a better pack. From a welding perspective, this includes:

1. Joining dissimilar materials
2. Addressing thicker tab materials
3. Achieving higher speed processing
4. Placement of welds with increased precision
5. Monitoring and recording process conditions

Laser and resistance welding address each of these challenges differently, and understanding those differences is essential in the determination of which method is more suitable for a given application.

Fig. 2 - Cylindrical cell battery pack

1. JOINING DISSIMILAR MATERIALS

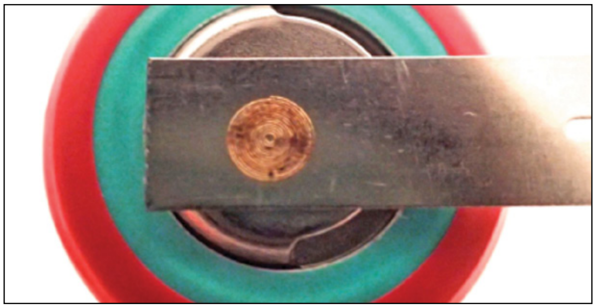

Fig. 3 - Nickel plated copper tab on CRS battery can

Cylindrical cells are predominantly manufactured with nickel-plated cold steel (CRS) using a drawn process. This is beneficial for the manufacturing of the shells, but decidedly not advantageous when considering the resistivity of the material and its current carrying capacity. For intercell connections, a more conductive material like copper or aluminum is preferred. The benefit of this combination is limiting energy loss in the system due to higher electrical resistance. From a welding perspective, however, it poses a challenge: joining dissimilar materials.

The challenges encountered in welding different metals include different melting temperatures, different expansion coefficients, and sometimes incompatible chemistry of the resultant weld. For example, aluminum melts at 660° C — fully 710° C lower than steels' 1370° C melting point. Managing the heat of each material to enter and maintain the liquid phase is challenging. Additionally, in a traditional fusion weld the aluminum and iron (from the steel) will form a brittle intermetallic weld nugget.

Some dissimilar materials and welding conditions can lead to success. Let's look at two strategies to enable resistance and laser welding of dissimilar materials.

Resistance Welding

In addition to the aforementioned difficulties, resistance welding conductive materials is further challenging because the fundamental heating process requires... resistance! It is possible to weld by increasing the current delivered by the power supply, but as current increases, so does the required mechanical force which can lead to overheating and deformation of the battery cell.

One solution is to use an engineered material of nickel-clad copper (for example, SIGMACLAD®) - which provides a more resistive material on the outside to facilitate the weld, lowers the current and force requirements and ensures metal compatibility - and copper in the middle to handle the desired higher current loads with less loss.

Laser Welding

When laser welding, electrical conductivity is a non-issue. The ability to weld dissimilar materials does, however, require an in-depth understanding of metallurgy, and, traditionally, not every combination is possible.

To overcome some of the metallurgical challenges of mixed materials, newer laser technologies such as single-mode fiber lasers combined with galvo scanning beam delivery or nanosecond pulsed lasers, have enabled the bonding of dissimilar metals that were previously deemed impossible. The reason these newer techniques have some success is due to limited interaction times, which, in turn, limit the amount of element migration and mixing of the two materials. However, the joints created are more like mechanical joints and need to be tested for fitness and purpose for the desired usage of the battery pack.

2. ADDRESSING THICKER TABS

As battery technology and design advances, manufacturers are employing thicker tabs to handle higher current loads, but the increased thickness poses challenges for both resistance and laser welding processes.

Resistance Welding

Thicker tabs make it difficult to supply resistance welding energy to the desired welding zone at the interface between the tab and battery can. Why? Because the current will naturally follow the shortest path with the least resistance, which means that it will remain in the tab material.

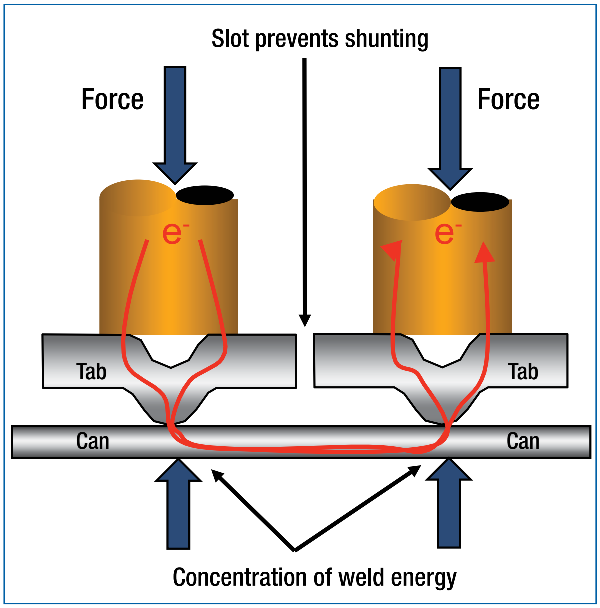

Fig. 4 - Cross section depicting projection, tab and battery can wall The electrodes provide force (F) to push the tab and battery can together. Current flows from the positive to the negative electrode.

To ensure the desired current path, the addition of slots and projections is recommended to direct the electrical current to the weld locations and provide enough energy to create a weld. The slots also help to prevent shunting, as the current takes the shortest path between the electrodes (Fig. 4). Projections focus the energy at specific locations, creating the weld at those locations. Without them, the energy distribution at the interface will be too large and won't generate enough heat to form the weld. However, this does not work in all cases. In general:

In general, for tabs up to 0.005" (127 microns) thick, projections are not required since the material is thin enough for the current to pass through it to the can. Projections may be used successfully when the tab thickness is between 0.005" (127 microns) – 0.020" (508 microns). When the thickness exceeds 0.020" (508 microns), however, it is not possible to reliably create and form the projections in the material. Furthermore, if the projections are too large, the force needed to collapse them during the weld will deform the batteries.

Laser Welding

For lasers, the challenge when welding thicker tabs is to achieve higher throughput with lower scrap.

The rule of thumb for laser welding is to weld thin parts to thicker parts. Why? Because the thicker material accommodates manufacturing tolerances better. The penetration of the laser beam into the thicker material can vary by +/-10% (or more) and still be safely within the bulk of the material without puncturing the battery can if the weld has too much energy, or failing to create the weld if the energy is too light. Thin material is more prone to weld defects because room for variation is restricted – thereby lowering production and increasing scrap. For Li-ion batteries (18650, 22700 and others), cell wall thickness is typically in the range of 250-350 microns. Ideally, the tab thickness should be the same or thinner – however, this runs contrary to the desire for higher current carrying capacity.

3. ACHIEVING HIGHER SPEED PROCESSING

Time is money and the demand for higher manufacturing throughput calls for welding methods that can deliver high-quality results in ever-shorter time frames. Both resistance and laser welding are capable of semi-automated or fully automated processing, but there are fundamental limits in the processing speed.

Resistance Welding

For resistance welding, processing speed is limited by the motion necessary to move the pack under the electrodes, and the electrode actuation to weld the different cells. After welding, motion is again necessary to move from cell to cell. The time needed to raise and lower the electrode to the weld location can be estimated at 1 second. In a direct comparison to laser welding, this is a significant amount of time and would strongly favor the laser process. Since the tooling requirements are lower, however, and because the electrodes actually make contact with the tab and push it against the cell, pack setup time is reduced, balancing the slower processing speed making resistance welding a viable manufacturing solution. Fig. 5 shows an image of a battery pack welding automated resistance welding system.

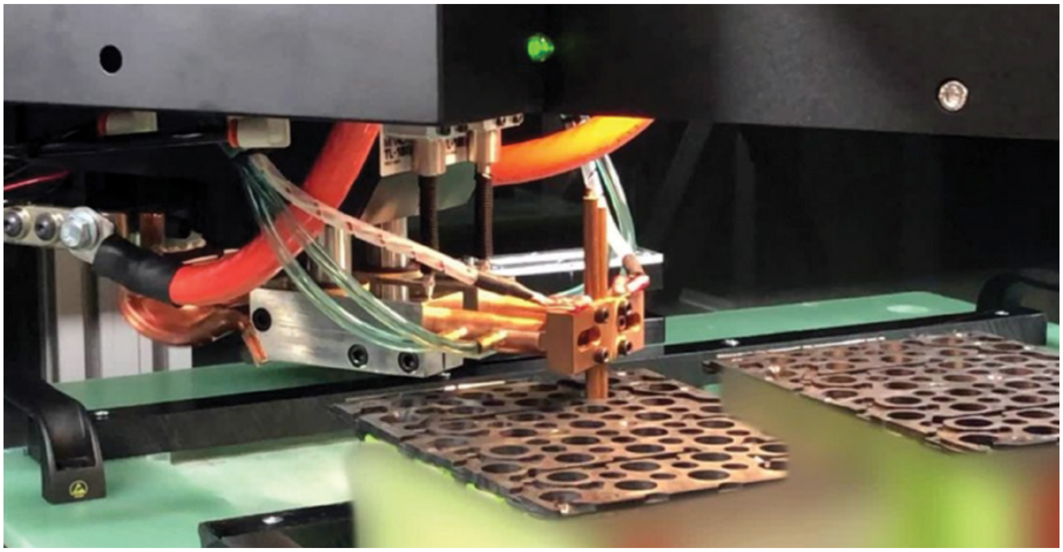

Fig. 5 - Automated resistance welding of a battery pack

Laser Welding

As previously mentioned, laser welding is a non-contact process which means that a fixture is required to hold the tab and parts in intimate contact. No time is necessary to raise or lower a head - assuming the manufacturing tolerances of the battery and fixture provide a consistent working distance.

Fixturing the batteries and tab material, however, is a challenge. For small packs, this can be relatively straightforward, but as pack size increases, the task of fixturing becomes more challenging. The design must accommodate manufacturing tolerances of the cells and remain flat across the entire module to ensure that the working distance is maintained. Fig. 6 shows a laser welding battery pack system with galvo scanning beam delivery.

Fig. 6 - Laser welding system for battery pack manufacturing

Table 1 - Estimated process times to weld example: 9R 13C cell module – or 234 total Welds (positive and negative terminals)

	RW	Laser - Fixed	Laser - Galvo
Motion from Cell to cell	1 s	1 s	1 ms
Motion from field to field*	N/A	N/A	6 sec * 4=24 sec
Head actuation (down)	0.5 s	N/A	N/A
Weld cycle time	200 ms	100 ms	20 ms
Head actuation (up)	0.5 sec	N/A	N/A
TOTAL (per site)	2.2 sec	1 sec	0.21 sec
TOTAL (234 welds)	514.8 sec	257.4 sec	73.14 sec

* in the case of galvo, assume total pack covered by Qty 4 6” x 6” fields. Motion between fields at 1ips.

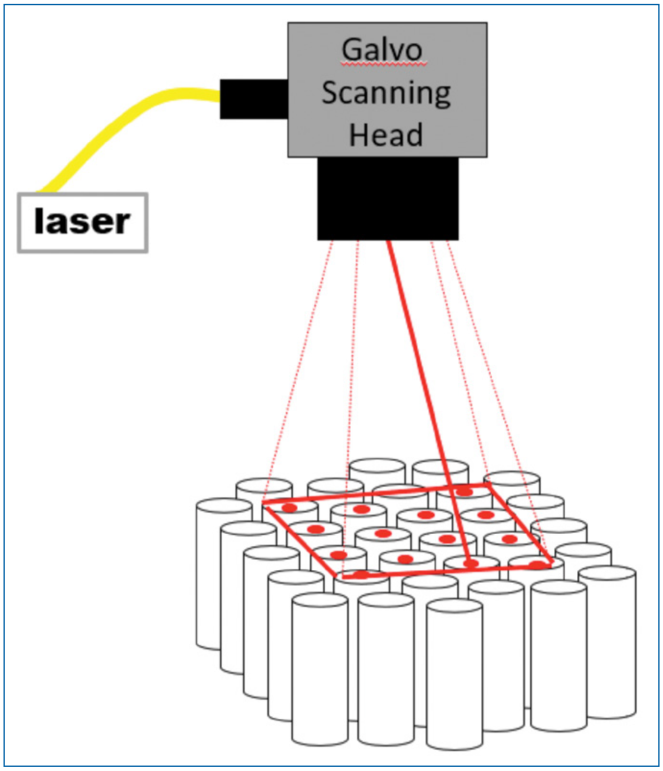

Fig. 7 - Graphic showing welding area (red outlined square) covering multiple cells that are within the field (red dots)

For battery packs, the tolerance of the working distance generally needs to be <+/- 0.5 mm, but in some cases, can be as small as <±0.25 mm. This value depends on the tab material and the laser type.

To achieve this, a pre-check is often employed prior to welding to ensure that the working distance is maintained. This adds a little bit of time, but the actual laser welding process itself is extremely fast – typically <100 ms – which counteracts that delay. In Table 1, this adjustment time is not provided in the comparison because it is a variable and is not needed in all cases.

To truly achieve higher processing speeds, a galvo scanning head can be used to quickly steer the beam from cell to cell. The jump speeds are negligible compared to the motion of an XY table or gantry. The limitation is the field size of the lens. This type of laser welding solution needs to adjust for the manufacturing cell heights and fixturing. It also requires additional pre-weld distance and position checks that add time.

If the pack size is larger than the welding field size, XY stage motion is also needed to address all of the cells. This could be indexed or “on the fly” motion where the galvo and linear motions are coordinated.

4. PLACEMENT OF WELDS WITH INCREASED PRECISION

Although it would seem that there is ample room to place a weld on the battery cells in a pack, the required precision of the placement is very high depending on the cell design.

Resistance Welding

When the positive and negative terminals are on opposite sides of the battery, resistance welding is a viable joining technology. As noted above, the positioning of the electrodes when slots and projections are used can be on the order of 100s of microns. The electrodes must span the projections (often two per side) without crossing the slot. Placement of the electrodes needs to be within 0.5 mm. This is achievable in an automated system using machine vision to locate features on the tab.

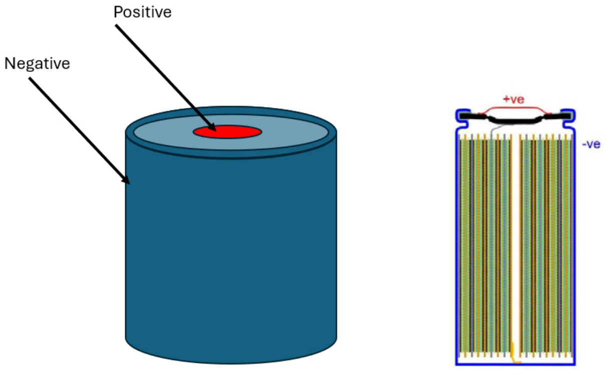

Fig. 8 - Battery cell designs with negative and positive terminals on the same side. The cell on the left shows an overview of the two poles. The cell on the right shows a cross-section of the battery tab and each terminal.

Laser Welding

The spot size of a laser weld is extremely small (0.05-0.4 mm) in comparison to the weld location area (>1 cm^2) when the positive and negative terminals are on opposite sides of the battery. Since the tab design does not need to include slots and projections, positioning is not a concern in this configuration.

One common battery pack design has positive and negative terminals conveniently located on the same side, eliminating the need to flip it during assembly. But the edge of the can, where the negative terminal is located, is very narrow. The landing area on the edge of the cell depends on the size, but for 18650 cells it can be on the order of 1 millimeter.

To make matters worse, the area of the negative ring is often masked by the tab material. This can be challenging even when employing machine vision systems.

It is not possible to join this type of geometry with resistance welding, but is possible with a laser since its focal spot can be on the order of 25-50 microns. Because the edge of the cell is rolled, there is only a narrow width where the tab makes good contact with the terminal. If the laser is too far in or out from the center of the cell, it will cut the tab since there is no backing material. Machine vision is required for precise positioning of the welds.

5. MONITORING AND RECORDING PROCESS CONDITIONS

In any welding process, consistency is the key to success. Unfortunately, any number of things can go wrong, all caused by variations in one or more of these areas:

- Equipment performance
- Material properties
- Process settings

The ability to monitor, judge acceptability, and record the data provide valuable insight into the welding process and can capture defects early.

Fortunately, equipment exists for both resistance welding and laser welding that can capture key process parameters, instantaneously judge them versus a known good reference, and record the data.

Weld process monitors enable manufacturers to detect defects during the welding process, alerting operators and engineers to potential production issues. In addition to comparing measurements, monitors offer a means to record and store process information for product traceability.

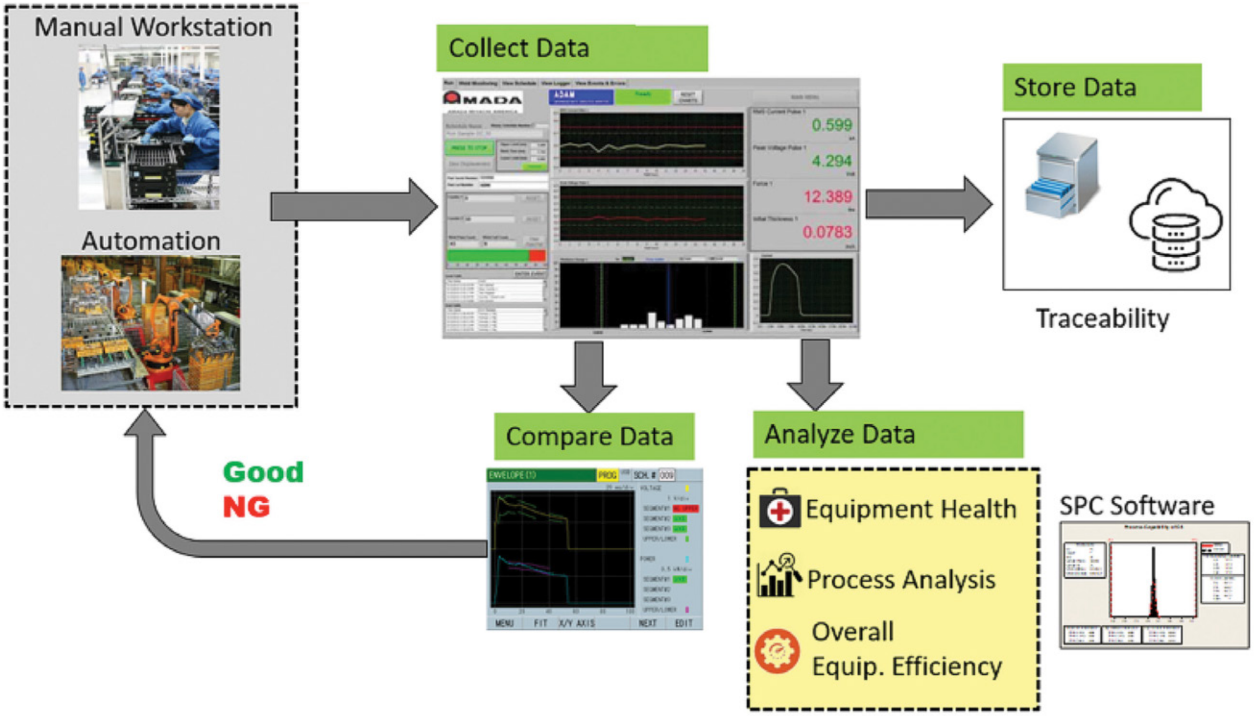

Fig. 9 - Concept of weld monitoring and data flow from a weld monitor.

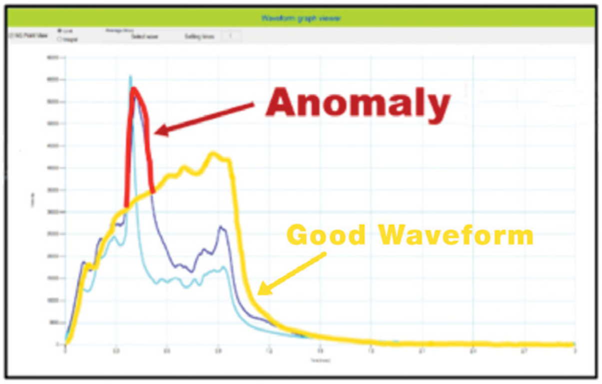

Fig. 10 - Weld Fault detection - comparison of known good reference signal versus "anomalies" that fall outside expectation.

In short, monitors measure the key parameters that determine the success of a weld. By comparing new measurements to a known good reference, welds producing significant deviations can be flagged as unsuccessful and further reviewed. In our experience, the data collected by these devices can tell a story that even the most well-trained eyes and ears of an experienced operator cannot. Even when it is obvious that the weld is not working, the operator may not be able to pinpoint the root of the problem, whereas the data from a monitor could. Without this measured data, the operator is largely running blind and making guesses at the root of the problem.

Resistance Weld Monitors

Resistance weld monitors measure electric current, voltage between electrodes, electrode force, and electrode movement during the welding process. These measurements can be compared to known good values making an instantaneous judgement of the weld. Basic models output a numeric aggregated value (e.g. min or max) for one or more parameters. These are often sufficient for basic data analysis and identification of welds that exceed set limits.

More advanced monitors can capture and analyze the entire, high-resolution waveforms of every parameter during the weld cycle. Waveforms display the signal versus time and provide better insight into the weld process dynamic than do the simple aggregated values. They can tell not only whether the limit was exceeded, but also when the violation happened. For example, sparking can occur due to improper force at the beginning of the weld or poor part fit up during the weld. The waveform can capture these parameters and identify which issue is at the root of the sparking.

Laser Weld Monitors

Laser weld monitors provide good/no good evaluation by collecting and comparing signal occurring during the welding process. The intense laser-matter interaction creates a broad spectrum of signals including infrared (IR), visible, back reflection and acoustic signals. By analyzing and comparing signals, these devices can capture production defects like gap between parts, out-of-focus conditions, lack of cover gas, and incorrect part/material.

CONCLUSION

Battery pack manufacturing continues to evolve and new designs bring new challenges for manufacturing - including the welding connections of the tab material to the cells.

This article presented five different challenges that appear in modern battery pack manufacturing.

1. Joining dissimilar materials
2. Addressing thicker tab materials
3. Achieving higher speed processing
4. Placement of welds with increased precision
5. Monitoring and recording process conditions

Resistance welding and laser welding can address a majority of these new challenges - with some limitations. As manufacturing engineers consider new pack designs, it is important to consider the joining process and understand the implications of different technologies. Selection of the right equipment goes beyond these new challenges - and also included budget and throughput. Consultation with vendors is recommended to help navigate these decisions.