UNIQUE, COST-EFFECTIVE NON-WELDING TECHNIQUE FOR BATTERY ASSEMBLY IN ELECTRIC VEHICLES

A Frost & Sullivan White Paper
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The electric vehicle (EV) industry relies heavily on the joining technologies of battery cells to meet the desired power and energy density. Joining technologies should have good electrical conductivity and be able to withstand harsh driving environments such as vibrations, severe temperatures, and the possibility of surviving a crash. The assembly of EVs involves standard welding techniques such as ultrasonic (38% of total share), laser (35% of total share), and resistance (26% of total share).

Ultrasonic welding accounts for the largest share in EV battery assembly due to its predictable quality and performance for both thin and thick electrodes. The presence of solid-state bonds makes it suitable for joining different materials, and the system can be easily automated at low cost. However, the biggest problem with ultrasonic welding is parasitic vibration due to exposure to high-frequency sound (20kHz), which can lead to structural integrity issues. Resistance welding is suited for thin electrode battery tabs and medium-powered capacity applications such as power tools and notebooks. On the other hand, laser welding is most appropriate for thick electrode battery tabs and high-powered applications such as EVs that require a thicker tab to support higher voltage flow from the battery pack.

Good welding depends on a multitude of factors, including temperature, angle, dwell time and type of material. Ultrasonic and laser welding techniques involve a high degree of R&D as both technologies have flexible parameters, primarily dwell time and type of materials. Commonly used materials include copper and nickel. While copper provides less resistance loss; nickel has better corrosion resistance than copper and is easy to weld.

Welding techniques, however, come with several significant challenges, including:

- Low product stability when there is continuous vibration.
- Welding process must be precise, usually using a highly automated machine, as any improper connection or micro-crack could lead to Joule heating (or resistive heating) causing the battery system to break down.
- Poor balance between cells. Balancing of the cell is crucial because paralleling two or more cells of significant different voltages (normal range between 3.6 Volts and 3.8 Volts) could cause an instantaneous and massive current flow in the direction of the lower voltage cell, damaging the cells and potentially causing a fire in the worst-case scenario.
- High capital cost for welding equipment (laser welding equipment costs nearly USD200,000).
- Complex maintenance and recyclability of the EV battery. Since welding is a permanent joining process, battery maintenance and recycling require a destructive method.
- Brittleness of the welding seam. The dissimilarity of the metals mix increases the brittleness of the welding seam. A brittle seam is not acceptable in a vehicle exposed to vibrations due to engine movement or road conditions.
- Too much heat during the welding process may destroy the battery, whereas deep welding can cause chemicals inside the battery to leak out, which is hazardous to humans and the environment.
- Welding technique may cause unequal thermal masses leading to uneven current flow and disrupting performance.
There have been various efforts to improve welding and non-welded techniques. For example, researchers from the Warsaw University of Technology have developed small-scale resistance welding. Small-scale resistance welding has diameters of less than 1mm. Due to the low electrode force (around 50N), small-scale resistance welding has high-current intensity and very short welding time (milli- and microseconds). This results in a very small heat-affected zone, reducing thermal stresses, which are the leading cause of cracks in joining.

Fraunhofer ILT has developed an innovative joining technique by using a single-mode fiber laser incorporated with spatial power modulation. The innovation allows the manufacturer to control weld depth especially during direct welding to the negative terminal of the battery. This is because the negative terminal has low thickness at around 0.015 inch (0.3mm), making it prone to punctures.

*Figure 1: Welding Seam for Fraunhofer's Joining Technology (Source: www.ilt.fraunhofer.de)*

Manz AG has developed laser welding via a high-frequency overlap local modulation with automatic calibrator. This laser technique is able to keep the penetration depth constant and reduces material mixing in the welding spot, decreasing the brittleness of the seams. This technique also allows wide width flexibility, from 0.1mm to 1mm.
In terms of non-welded techniques, Headway, a family-owned business from the US has produced a cylindrical cell with factory-attached thread points at both ends of the cylinder. Cell-to-cell assemblies are done using conventional bolts and nuts. To connect the wire to ring terminals, the assembler may opt for the soldering technique or crimp tool. This is popular among hobbyists looking for do-it-yourself (DIY) battery assembly.

*Figure 3: Headway Assembly Kit (Source: endless-sphere.com)*
Greenlion, a project under the European Commission has developed a green modular battery assembly using either epoxy or polyurethane. However, this method is only suitable for the pouch cell type.

Figure 4: Summary of GREENLION’s Module Design and Assembly Process
(Source: www.greenlionproject.eu/project-overview)

Eclimo has developed a non-welded technique based on a pure copper plate as the current carrying component, eliminating problems associated with welding assembly. This type of assembly addresses the major problems with welding including:

- Contact between the conductive material and electrode tab is maintained using a pressure plate. This technique ensures full contact between cell and conductor, therefore eliminating a low spatial efficiency problem that is common with welding processes, leading to electrical stability. The plate is also able to act as a protector, increasing the reliability of the joining technique against vibration and temperature.

- The technique is able to maintain the manufactured cell capacity because it does not induce any thermal stress. A short burst (less than 60 seconds) of thermal stress from the welding process on the lithium ion battery is detrimental to the battery performance because it can cause electrolyte decomposition and changes to solid-electrolyte interface (SEI) characteristics, causing an increment in impedance and inducing self-discharge.

- Addresses poor balance between cells by ensuring continuous connection between the battery cap and the conductor. This is achieved by spreading the charge concentration to the whole cap, reducing heat concentration at the connector and allowing better heat dissipation to keep battery temperature within the optimum range recommended by the manufacturer. This leads to better stability of the battery pack.
The technique is cost-effective as it reduces the need for a highly-skilled worker as required by the welding process, and instead uses a mechanical fitting that can be assembled manually. Furthermore, Eclimo utilizes efficient over-the-shelf technologies to bring costs down. Every component is readily available from local manufacturers. To be comparable with other manufacturers, Eclimo aims to automate the system to be on par with industry standards, where the system is able to process a single cell every two seconds (rate is based on the GM Battery Assembly Plant).

Simplify the maintenance and recyclability since the connection is based on mechanical fitting so that the battery can be easily disassembled. Recyclability is important because the conservative value for an EV’s battery end-of-life is when the battery capacity fades to 70% to 80% of the original capacity. Recyclability of battery allows for easy configuration of the battery for secondary use, such as portable energy storage (e.g., to replace diesel/petrol generator set). According to an EU Directive, the recycling process of lithium ion batteries should be at least 50% of the average weight of the whole Li-ion battery in terms of construction element and materials.

Eclimo’s technology maintains the safety of the assembly process by eliminating the possibilities of puncturing the cell and high thermal stresses.

**Figure 5: Eclimo Power (Source: Eclimo)**

Eclimo’s novel design has received a patent from the Australian Patent Office, whereas two patent applications are pending approval, one from the US and another from Malaysia. The patent has also received two forward citations from patents registered in the US Patent Office (number of forward citations received by a patent is often used as a measure of the patent’s significance). Aside from the advantages above, in this patent, Eclimo introduces a U-turn configuration that joins the battery cells without using any external electrical connection. This configuration maintains the internal resistance of each battery pack and further simplifies the installation and maintenance process.
Eclimo’s non-welded technique increases the weight of the battery pack by 10% to 15% (an Eclimo battery pack consists of 7 modules and weighs 25kg). An additional 2.5kg to 3.75kg can be considered significant for a system that has an overall weight of 155kg (weight of a scooter). The extra weight is due to the other structures (i.e., pressure plate, silicon rubber, and aluminum-customized heatsink) to dissipate heat evenly during the discharge process. However, the greater heat dissipation achieved by Eclimo’s method is essential for EVs that typically have rapid acceleration and deceleration releasing a substantial amount of heat that may disrupt the battery performance.

The non-welded technique is only suited for high-powered batteries (3kWh and above) because the system requires a large area to balance the voltage flow of the cells. Therefore, this type of assembly is only suitable for EVs or stationary energy storage. In stationary energy storage, the battery should be able to handle high power ramp rate, usually in 2MW step and able to slow decrement of State of Charge (SoC) by reducing internal losses of auxiliary components. However, the proper balance of cell is necessary to prevent a short circuit especially hard short circuit, which could cause permanent damage to the cell. Conductivity and power losses between non-welded and welded techniques are roughly the same.
ECLIMO’S NON-WELDED TECHNIQUE VS ULTRASONIC WELDING

To compare Eclimo’s Non-Welded Technique against the welded method objectively, this report utilized the Analytical Hierarchy Process (AHP; a multiple-criteria decision-making tool). The tool is used to compare Eclimo’s Non-Welded Technique with ultrasonic welding, the most commonly used welding method in EVs.

Figure 7: Flowchart of AHP Process

The comparison is based on 9 main criteria identified as crucial characteristics for battery assembly.
### Table 1: Explanation of Criteria

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<th>CRITERIA</th>
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<td>ABILITY TO SUPPORT HIGH VOLTAGE FLOW</td>
<td>Batteries in electric vehicles utilize high voltage (at least 370V) to power the powertrain. The joining technology should be able to handle this high amount of voltage flow.</td>
</tr>
<tr>
<td>ABILITY TO WITHSTAND HARSH ENVIRONMENT AND ROAD CONDITION</td>
<td>EVs are exposed to unexpected road conditions, for example, continuous vibration and heavy rain. Therefore, it is crucial for joining technology to handle constant exposure to these elements.</td>
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<tr>
<td>PROMOTE GOOD CELL BALANCING</td>
<td>Balancing of the cell is essential because paralleling two or more cells of significant different voltages (average range between 3.6V and 3.8V) could cause an instantaneous and massive current flow in the direction of the lower voltage cell. This can damage the cells and even result in a fire in the worst-case scenario.</td>
</tr>
<tr>
<td>PROMOTE GOOD HEAT DISSIPATION</td>
<td>Joining technology that promotes good heat dissipation is desirable because EVs release a substantial amount of heat during rapid acceleration-deceleration, and the charge-discharge cycle may disrupt the battery performance.</td>
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<tr>
<td>ABILITY TO MAINTAIN STRUCTURAL INTEGRITY OF THE CELL</td>
<td>The joining technology should maintain the structural integrity of the cell to prevent the possibility of leakage. Leaking may lead to an explosion in the worst-case scenario.</td>
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<tr>
<td>LOW CAPITAL COST</td>
<td>Low capital cost of joining technology is desirable to bring down the total cost of battery module production.</td>
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<tr>
<td>COMPLEXITY OF THE PROCESS</td>
<td>Joining technology that is easy and safe is desirable because it reduces the need for skilled workers, lowering total cost.</td>
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<tr>
<td>PROMOTE EASY RECYCLING PROCESS</td>
<td>Recyclability is important because the conservative value for an EV's battery end-of-life is when the battery capacity fades to 70% to 80% of the original capacity. Easy battery recyclability allows for easy configuration of the battery for secondary use, such as portable energy storage (e.g., to replace diesel/petrol generator set).</td>
</tr>
<tr>
<td>EASY MAINTENANCE</td>
<td>Joining technology that promotes easy maintenance of the cell is desirable to provide peak storage capacity continuously.</td>
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Figure 8 compares Eclimo’s non-welded method against ultrasonic welding, based on the criteria above. The graph clearly shows that Eclimo’s Non-Welded Technique is far better or at least offers the same performance as ultrasonic welding for all criteria. The superiority in all criteria has led to a final priority value (Figure 9) favoring Eclimo’s Non-Welded Technique by a huge margin (62.7%).

**Figure 8: Comparison of Eclimo’s Non-Welded Technique vs Ultrasonic Welding based on 9 Pre-Selected Criteria**

- **Ability to Support High Voltage**: 50% Eclimo Non-Welded, 50% Ultrasonic Welding (50%)
- **Ability to Withstand Harsh Environment and Road Condition**: 20% Eclimo Non-Welded, 80% Ultrasonic Welding (80%)
- **Promote Good Cell Balancing**: 50% Eclimo Non-Welded, 50% Ultrasonic Welding (50%)
- **Promote Good Heat Dissipation**: 33.3% Eclimo Non-Welded, 66.7% Ultrasonic Welding (66.7%)
- **Ability to Maintain Structural Integrity of the Cell**: 25% Eclimo Non-Welded, 75% Ultrasonic Welding (75%)
- **Low Capital Cost**: 12.5% Eclimo Non-Welded, 87.5% Ultrasonic Welding (87.5%)
- **Complexity of the Process**: 16.7% Eclimo Non-Welded, 83.3% Ultrasonic Welding (83.3%)
- **Promote Easy Recycling Process**: 16.7% Eclimo Non-Welded, 83.3% Ultrasonic Welding (83.3%)
- **Easy Maintenance**: 16.7% Eclimo Non-Welded, 83.3% Ultrasonic Welding (83.3%)
In developing a unique yet proven non-welded assembly technology, Eclimo continues to challenge the status quo by tackling critical challenges plaguing welding processes. Eclimo’s Non-Welded Technique is a superior alternative for users seeking a stable (physically and electrically) method that is reliable and does not require high capital. As welding processes account for 16% of the overall variable manufacturing cost of a battery system, Eclimo’s low-cost system is a worthwhile replacement technology.

Eclimo’s consistent R&D efforts augur well for the company’s growth, fortifying its position as one of the leading innovators in the non-welded battery module segment.

“The electric vehicle industry relies on the joining technologies of battery cells to meet the desired power and energy density for such vehicles. Eclimo has developed a unique yet proven non-welded assembly technology that is able to challenge the status quo by tackling critical challenges plaguing welding processes in 3 main areas – electrical stability, physical reliability and cost – while promoting environment sustainability. As welding processes account for 16% of the overall variable manufacturing cost of a battery system, Eclimo’s low-cost system is a worthwhile alternative technology.”
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Brittle welding seam in an EV can result in micro-cracks and overheating due to vibrations from engine movement or road conditions causing the battery system to malfunction.

Cell imbalance could result in massive current flow damaging cells and potentially causing a fire.

Complex maintenance and recyclability of the EV battery.

Thermal stresses from welding could destroy the battery, which is hazardous to humans and the environment.

**STANDARD JOINING TECHNOLOGIES**

Electric vehicles (EVs) rely on joining technologies of battery cells to meet the desired power and energy density. Battery assembly for EVs involves the following welding techniques:

- **ULTRA SONIC** 38%
- **LASER** 35%
- **RESISTANCE** 26%

Source: Industrial Laser Solutions for Manufacturing

**COMMON CHALLENGES**

Eclimo’s non-welded technique uses mechanical fittings as the joining method, eliminating issues associated with welding assembly. Key benefits:

- **STABLE.** Better electrical stability in joining by using pressure plates that mechanically fitted to maintain continuous contact between conductive material and electrode tab to ensure good balance between cells especially in the event of extreme vibration and temperature. This improvement result in:
  - Ability to Maintain Structural Integrity of the Cell 75%
  - Promote Good Cell Balancing 50%
  - Ability to Withstand Harsh Environment and Road Condition 80%
  - Ability to Support High Voltage 50%

- **LOW COST.** Eclimo relies on mechanical fitting process that easily assembled by low skilled workers. Each component is an over-the-shelf technology that available from local manufacturers and, for fuss-free maintenance and recyclability. This improvement result in:
  - Easy Maintenance 83.3%
  - Promote Easy Recycling Process 83.3%
  - Low Capital Cost 87.5%

- **SAFE.** Eclimo’s non-welded technology maintains the safety of the assembly process by eliminating the possibilities of puncturing the cell and high thermal stresses. It also utilized U-turn module configuration that joins battery cells without external electrical connections simplifying installation, maintenance and eliminating thermal stress to keep the battery at manufacturer-recommended temperature. This improvement result in:
  - Complexity of the Process 16.7%
  - Promote Good Heat Dissipation 83.3%
  - Complexity of the Process 66.7%
  - Promote Good Heat Dissipation 33.3%