TECHNotes

Published by Buehler, a division of Illinois Tool Works

Volume 9, Issue 7

Metallurgical Challenges in EV Battery Pack Manufacturing

Lithium-ion battery packs, are at the core of the electric vehicle (EV) revolution. As engineers push for higher energy density, faster charging rates, and longer life cycles, they face a range of complex metallurgical challenges. Understanding these challenges is critical to improving battery performance, safety, and longevity.

Figure 1. Exploded view of high voltage battery pack system

Figure 2. a BEV platform system

The Anatomy of a Battery Pack

At its core, the battery pack is an intricate assembly of individual cells organized into modules, housed within a robust pack structure. Each cell consists of:

- **Cathode (the energy workhorse):** Common materials include nickel-manganese-cobalt oxide (NMC), Lithium Iron phosphate (LFP).
- **Anode (the ion host):** Typically made of graphite, hosting lithium ions during charging.
- **Electrolyte (the lithium highway):** Can be a solution, gel, or solid-state material in next-gen batteries.
- **Separators (the silent guardians):** Prevent direct contact between the cathode and anode while allowing lithium ions to pass.

Each component presents unique metallurgical challenges. Scaling up to the battery pack level, considerations extend to current collectors, busbars, and cooling plates, where welding and material selection become increasingly complex. This article will highlight the key areas where metallographic analysis is fundamental to the understanding of these components.

1. The Challenge of Dissimilar Metals

EV battery packs incorporate a variety of metals—aluminum (Al), copper (Cu), nickel (Ni), and steel (Fe)—each with unique properties:

- **Aluminium:** Lightweight but prone to oxidation.
- **Copper:** Excellent conductivity but highly reflective to laser welding.
- **Nickel:** Corrosion-resistant but introduces residual stresses.
- **Steel:** Strong but difficult to bond with aluminum.

Figure 3. Schematic of Al-Cu weld highlight features expected when Al melts and Cu remains in solid state (Zwicker 2020)

Welding these dissimilar metals introduces **intermetallic compounds (IMCs)**, brittle phases that weaken mechanical strength and increase electrical resistance. Minimizing IMC formation through precise process control is crucial for reliable battery performance.

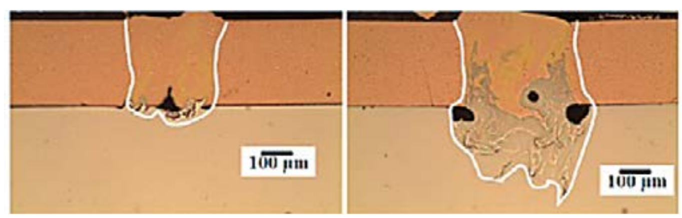

Figure 4. a laser welded profile of a Cu-Al busbar sample and related defects (Voids, IMCs) (Kumar, WMG)

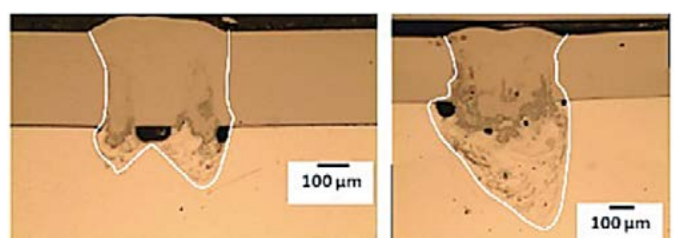

Figure 5. A laser welded profile of a Ni-Al busbar sample (voids, IMCs) (Kumar, WMG 2021)

Recent studies highlight the **role of process optimizations**, such as laser beam offset towards steel in Fe-Cu welding, and the use of interlayers like Ni, Zn, and Sn to mitigate Fe-Al reactions. In Al-Cu welding, pulsed lasers and sinusoidal beam oscillation have been shown to suppress excessive IMC growth, enhancing mechanical and electrical properties.

2. Welding Woes: Too Hot to Handle?

In the battery world, the wrong welding technique can mean higher resistance, weaker joints, or a catastrophic failure. The three main contenders in EV battery welding are:

- **Laser Beam Welding (LBW):** Precise and fast but struggles with reflectivity and deep penetration. New green and blue lasers are improving energy absorption on Cu and Al surfaces.
- **Ultrasonic Welding (UW):** Ideal for delicate aluminium-copper joints, but excessive vibration can damage battery cells.
- **Resistance Spot Welding (RSW):** Reliable but less effective on high-conductivity materials like aluminium and copper.

3. Managing Thermal Expansion

Materials like aluminium expand twice as much as steel when heated. If not accounted for, the stress induced at weld joints can lead to cracking, delamination, or fatigue failures over time.

Using Ni-coated interlayers has been shown to minimize stress in Al-Cu and Fe-Al welding, improving overall joint longevity. Cooling techniques, such as Cu backing plates, have also been effective in controlling thermal expansion effects.

4. Addressing Corrosion Risks

Battery modules live in a harsh environment - exposed to temperature swings, humidity, and even road salts. Galvanic corrosion is a major issue, especially where aluminium meets copper or steel.

Resistance sport welding (RSW) | Ultrasonic welding (UW) | Laser beam welding (LBW)

***Figure 6**. The common welding techniques of cell interconnects, (Martin J. Brand, 2015)*

Recent studies highlight the use of Zn coatings and interlayers to prevent Al-Fe corrosion and silver coatings for Al-Cu connections. Additionally, Pb and Sn interlayers have shown improvements in corrosion resistance and mechanical stability.

5. The Future: Smarter Metallurgy, Smarter Batteries

Ongoing research is driving innovations in battery pack manufacturing, including:

- **Hybrid welding techniques** (combining laser and ultrasonic welding).
- **Advanced coatings and interlayers** to mitigate IMC formation.
- **Real-time weld monitoring with AI** for defect detection.
- **New alloy compositions** that improve metallurgical compatibility.
- **Laser beam wobbling and sinusoidal oscillation techniques** to control IMC growth and heat distribution.

Final Thoughts: Metallurgy Matters!

EV battery packs are complex assemblies requiring precision engineering and a deep understanding of materials science. Optimizing metallurgy and welding processes is essential for improving battery reliability and efficiency.

For further queries please contact us on **lab.eu@buehler.com** **lab.us@buehler.com** or our website at **www.buehler.com** and for solutions applicable to automotive industry.

Let's collaborate - one microstructure at a time.
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