Knurl Design Optimization for Foil-to-Tab Welding in Lithium-ion Battery Cells

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Ultrasonic metal welding (UMW) is widely considered the best process for joining multiple layers of thin foils to a lithium-ion battery tab. UMW tools used to weld these delicate joints must be designed to minimize damage of the extremely thin foils while creating strong welds.

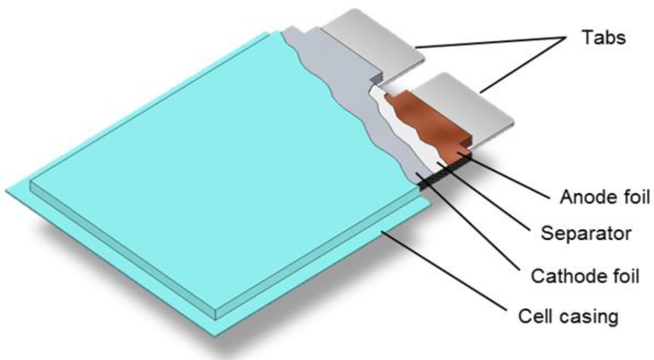


Figure 1 – Cutaway diagram of a pouch-style lithium-ion cell showing the foil-to-tab joints

Why is Foil-to-tab Joining Important?

In lithium-ion (Li-Ion) pouch-style battery systems, foil-to-tab welds connect all the current-collector plates inside a battery cell and join them to a tab which exits the casing and allows the cell's energy to be transferred to an external device. There are typically two foil-to-tab welds in a single cell and multiple cells in a battery system. Since these cells use series and parallel connections, a single joint failure will compromise the output of the entire system. Foil-to-tab joints are especially challenging because they are often made up of dissimilar metals, material thicknesses are mismatched, and one side of the joint is solid while the other is made up of multiple layers as thin as 10-μm each.

Possible Joining Solutions

Both resistance spot welding (RSW) and laser beam welding (LBW) technologies can be used; however, characteristics inherent to each of these processes make them non-ideal for this application.

RSW relies on the electrical resistance of the materials being joined to generate the heat required for welding, with interface and bulk resistance both playing a part. Since the low bulk resistance of the aluminum and copper foils makes it difficult to generate sufficient heat for joining, heating often relies on interface resistance. Metal oxides increase interface resistance, promoting heat generation; however, aluminum requires significant deformation at the interface to break its brittle and highly stable oxides and achieve the metal-to-metal contact required for solid state bonding. In contrast, copper oxides are malleable and are readily adsorbed. In this case, the level of deformation required is significantly less than for aluminum, and bonding relies more on achieving an adequate thermal cycle. UMW doesn't rely on bulk resistance and inherently scrubs away oxide layers as part of the process.

LBW is sensitive to gaps between material layers in the weld joint. As a general rule of thumb, the gap should be less than 10% of the material thickness. For the 13-μm thick foils commonly used in battery cells, a gap of 1.3 μm is difficult to achieve and requires excessive fixturing. In addition, to avoid cutting of the thin material, LBW often requires a thicker sacrificial tab to cover the top foil layer. Because UMW is self-clamping, gaps are not an issue and quality welds can be made without a sacrificial tab.

UMW Tool Design

Manufacturers often overlook the importance of UMW tool design. This includes the geometry of the knurl which grips one side of the weld joint and provides the mechanical motion required for welding. Industry has adopted tool designs which were originally intended for the joining of two layers of thicker material; however, these tools are not well-suited for joining multiple layers of thin, delicate foils to a tab. The sharp, closely packed knurls of a traditional design cut and tear the thin foils if excessive weld energy is used and fail to make a weld if insufficient energy is applied. This leaves the manufacturer with a narrow or non-existent process window within which strong, damage-free joints can be produced.

The EWI Approach

In 2013, EWI developed and proved the feasibility of a novel UMW tool design which significantly improved the quality of these joints and allowed multiple-layers to be joined in a single operation.1 In addition, this tool facilitates joining without pre-consolidation of the foils and without the use of buffer material or thicker sandwich foils.

EWI recently completed an optimization study which varied three critical knurl design features and measured their effects on weld quality. The critical variables were knurl height (x) as it relates to the foil stack thickness, knurl angle (y), and knurl spacing (z) (Figure 2). Each variable was independently evaluated and the optimum design was down-selected for a comparison with an industry-standard cross-hatch knurl design. The EWI design performed well with both aluminum and copper joints. For aluminum joints the new design yielded stronger welds with less foil damage. For copper joints, the strength was comparable, foil damage was significantly reduced, and the amount of weld energy required was reduced by 62% (Figure 3).

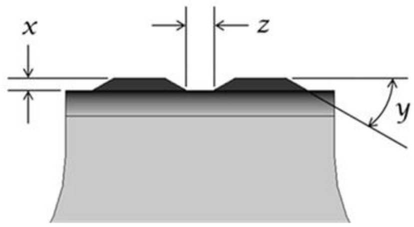
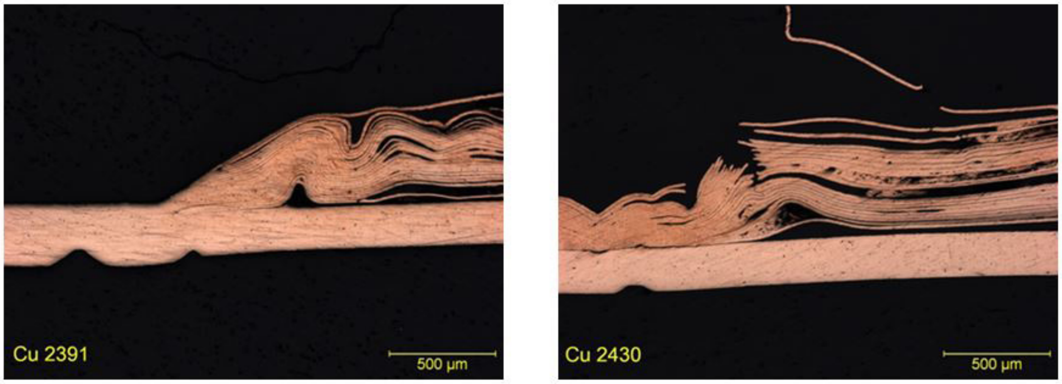


Figure 2 – Knurl design variables from EWI study



(a) EWI Knurl Design **(b) Industry Standard Knurl Design**

Figure 3 – Metallographic cross-sections of welded copper samples

1) http://ewi.org/ultrasonic-metal-welding-for-lithium-ion-battery-cells/

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