Quality Improvement in Battery Pack Assembly: The Role of Laser Cleaning in Optimizing Ultrasonic Wire Bonding Process

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Due to the challenges of welding dissimilar materials and difficulties inherent in joining fine wires to very thin sheets, ultrasonic wire bonding (UWB) is the technology-of-choice for electric vehicle (EV) battery packs. It excels in achieving strong, reliable electrical connections while minimizing heat-induced damage to sensitive components, which is crucial for preserving device integrity. In UWB, high-frequency vibrations (e.g., 60 kHz) with low amplitudes (typically a few microns) are used to generate oscillating shears between the wire and the metal sheet to create solid-state bonds. While this process does not require high power and the weld cycles are very short, it is compatible with the wide range of conductive materials (e.g., copper, aluminum) used in a lithium-ion battery pack. It offers high reliability and creates strong, enduring bonds between wires and bonding pads with low resistance.

UWB has a lot of advantages, but the fast cycle time and limited disruption of the material require tight control of surface cleanliness and roughness to maximize wire bonding performance. Because cleaning can be a burdensome and time-consuming task, ensuring a well-prepared surface for bonding during manufacturing is desired. To address these challenges, EWI recently investigated the use of an emerging laser cleaning technology to determine its effectiveness on the bond quality in UWB joining of aluminum wires to nickel-plated steel cells.[1]

Research Approach

In this study, the EWI team designed a robust experimental set-up and conducted initial investigations of the cleaning and wire bonding parameters to set the limits of the experiment. Next, a design of experiment (DOE) was created to efficiently plan the work using a multilevel resolution V design. Each coupon was tested for several responses including pull force. Finally, statistical analysis of the data was performed to assess the contribution of the variables and their interactions and to produce process robustness plots which were then used to optimize processing conditions for the studied range of parameters.

Experimental Setup

UWB technology was used to bond 250-µm diameter, pure aluminum wires to the positive terminals of nickel-plated, steel 21700 battery cells. Blasocut 2000 mineral oil was used to contaminate the battery cells. Once the battery cells were prepared, the Cobalt-xl-ev-100PF laser marking system developed by Laser Marking Technologies (Figure 1a) was used for laser cleaning procedure. Then, F&S BONDTEC wire bonder (Figure 1b) was used to ultrasonically bond the wires in loop configuration.

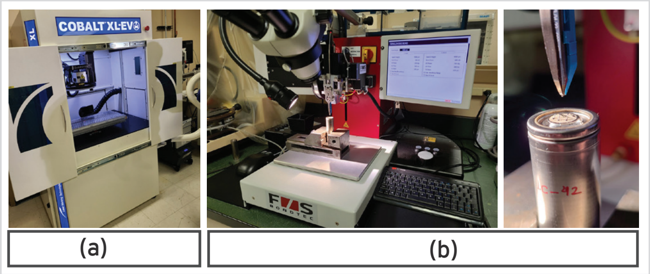

(a) (b)

Figure 1. Experiment setup a) Cobalt-xl-ev-100PF laser making system; b) F&S BONDTEC wire bonder

Optical microscopy was used to evaluate the quality of the bond and to measure the surface roughness of the samples before and after the laser cleaning process.

To assess the surface contamination before and after laser cleaning, JASCO 4700 Fourier-transform infrared spectroscopy (FTIR) was used to scan the surface of the battery cells. Finally, a Unitek wire bond pull tester was used to measure the bond strength of all samples.

DOE Organization and Data Analysis

The DOE used a multilevel resolution V design to create a 24-trial experimental plan to examine the effects of time, sample cleanliness, and surface roughness on bond strength.

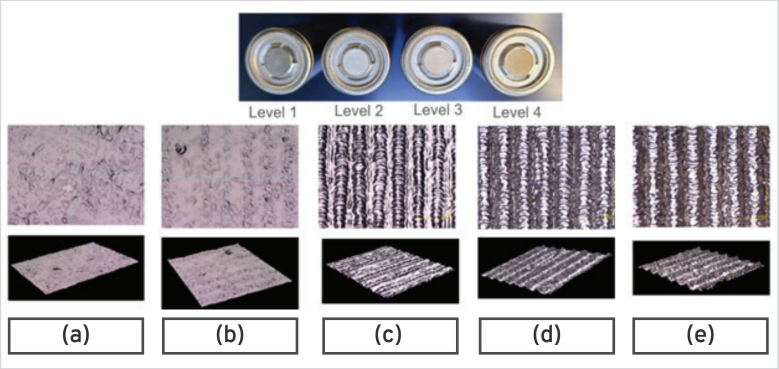
Table 1. DOE input factors and their levels

Factor/ level	**1**	**2**	**3**	**4**	**5**
Cleanliness	No oil	Oil			
Time (ms)	100	200	300	400	
Roughness	No cleaning (~1 μm)	1.2 μm	1.8 μm	3.4 μm	4.2 μm

Once the DOE was developed, the samples were cleaned with the laser and UWB trials were conducted. Evaluation of the strength of the bonded wires was done through pull-testing procedure. Finally, statistical analyses of pull-force data were done using standard EWI techniques, which include data normalization, regression curve fitting, and process robustness plot preparation.[2]

Results and Discussion

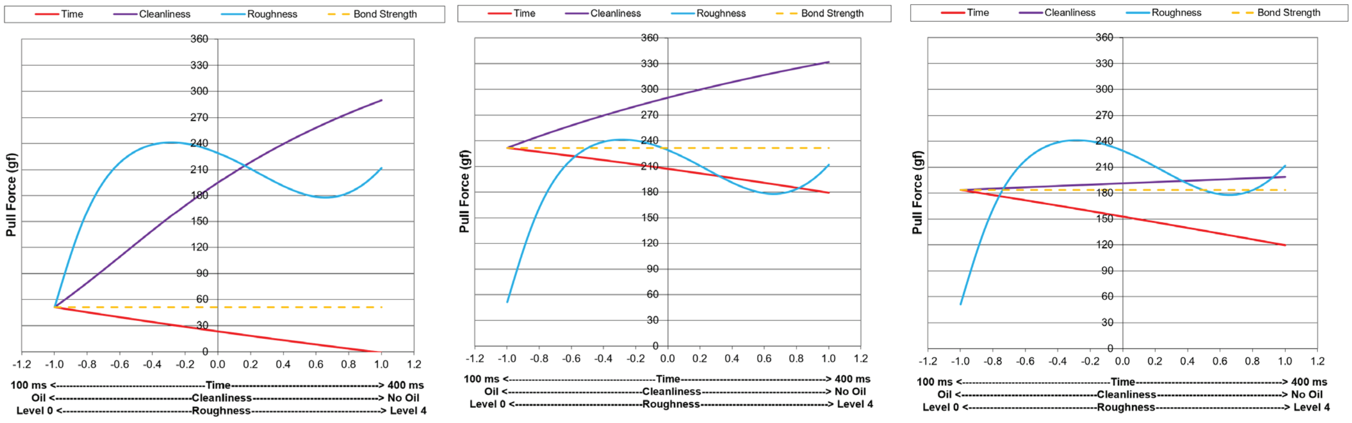
Figure 2 shows microscopic images with 1000x magnification as well as the measured surface roughness of the battery cells before and after laser cleaning using 4 levels of laser intensity. Moving left to right (from 2b to 2e), the direct effect of laser intensity on creation of peaks and valleys and rougher surface can be observed. Note the evidence of discoloration due to surface oxidation when higher levels of laser cleaning (e.g., level 4) were used.



(a) (b) (c) (d) (e)

Figure 2. Microscopic images of the surface of battery cells: a) as is (i.e., no laser cleaning) – Ra=1.0 μm; b) Level 1 – Ra=1.2 μm; c) Level 2 – Ra=1.8 μm; d) Level 3 – Ra=3.4 μm; e) Level 4 – Ra=4.2 μm

FTIR was used to evaluate and scan the surface of the battery cells for contamination after 1) cleaning the samples with isopropyl, 2) surface contamination with oil, and 3) laser cleaning. As expected, the FTIR results showed no evidence of contamination after cleaning with isopropyl. When the surface was contaminated with oil, oil spectrum was identified by matching it to paraffinic mineral oil spectrum in equipment's database. When the surface was cleaned with laser, the spectrum of the cleaned cell with laser was



Bond strength (gf)	Time	Cleanliness	Roughness
51.5	100	Oil	Level 0

Optimized Parameters

Bond strength (gf)	Time	Cleanliness	Roughness
231.7	100	Oil	Level 1

Bond strength (gf)	Time	Cleanliness	Roughness
183.5	100	Oil	Level 3

Figure 3. Process robustness plots: a) Level 0 (i.e., no laser cleaning); b) Level 1; c) Level 3

very similar to spectrum of the sample after cleaning with isopropyl. This data show laser cleaning can effectively clean the oil from the contaminated cells.

In Figure 3, process robustness plots show the effect of time, sample cleanliness, and surface roughness on the bond strength. The three plots demonstrate that to increase the wire bond strength, time should be minimized (i.e., level 1=100 milliseconds) and cleaned samples need to be used (i.e., level 2= no oil).

However, since elimination of contamination from battery pack assembly production line cannot be 100% guaranteed, our study evaluated the effectiveness of laser cleaning on the quality of the bond in UWB process of the contaminated cells with oil by considering the three levels of cleaning (i.e., Level 0 [no laser cleaning], Level 1 and Level 3) at optimized time (i.e., 100 milliseconds) for the studied range of time.

At level 0 (i.e., no laser cleaning, Figure 3a), the estimated bond strength is 51.5 gf. As level 1 laser cleaning (low intensity laser cleaning, Figure 3b) was used, the bond strength increased 4.5 times to 231.7 gf. Finally, using Level 3 of laser cleaning (Figure 3c) created 3.5 times stronger bonds compared to no laser cleaning case, and a 20% decrease in bond strength was observed compared to the bond strength obtained using low intensity laser cleaning (i.e., level 1). This negative effect of using higher intensity laser (i.e., level 3) on bond strength could be due to creation of surface oxidation and/or generation of a rougher surface. Overall, the obtained results show the effectiveness of laser cleaning technology for cleaning contaminated battery cells for maximizing wire bonding performance. Note that optimization of laser parameters is key to achieve the benefits of laser cleaning for UWB.

Conclusion

Laser cleaning technology can be successfully used to improve the quality of the bond in UWB process of aluminum wires to contaminated cells. All levels of laser cleaning studied in this work improved the quality of UWB joining by eliminating the oil from the surface of the battery cells thus improving wire bond strength. The highest bond strength was obtained when low-intensity laser cleaning was used.

The strength of the bonded wires decreased when higher intensity laser cleaning was used, which could be due higher surface roughness and/or creation of added oxidation at higher levels of laser cleaning which can be minimized by adding inert gas such as argon to the process. To learn more about how laser cleaning technology can be applied to clean your material prior to the bonding process to deliver higher quality bonds, please contact Amin Moghaddas at **amoghaddas@ewi.org**.

Note: *Any reference to specific equipment and/or materials is for informational purposes only. Any reference made to a specific product does not constitute or imply an endorsement by EWI of the product or its producer or provider.*

References

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2. Gould, Jerry. 2020. *EWI Guide to Design of Experiments for Engineering Challenges.* EWI. https://ewi.org/ewi-guide-to-design-of-experiments-for-engineering-challenges/

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