NEW LASER WELDING PROCESS FOR EXCELLENT BONDS

Laser welding in overlap (wobbling) promises more affordable Li-ion batteries

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E-Mobility will only become established when the energy storage units required in the car become more affordable – on this point the experts agree. The key here is lowering production costs. To accomplish this, the high-tech engineering company Manz is relying on a new type of laser welding in the production of lithium-ion batteries which is raising the bar for the quality of welding seams, process stability, and the required output of the beam source.

The production of Li-ion batteries requires multiple welding processes. Welded contact connections between the individual battery cells, for example, have proven to be more reliable, sustainable and above all cost-effective than bolted contacts or the use of bimetallic busbars. The boxes of the rigid battery geometries are also welded, because they have to be gas-tight up to a pressure of 40 bar. These types of welding connections must be entirely maintenance-free – electric cars should soon be able to drive in all climate zones, amid great temperature fluctuations and on all of the world's roads, whether good or bad.

Since each individual cell of a battery pack delivers just a few volts of voltage at high current, they must be connected in series to achieve a sufficiently high module voltage. The terminal contacts made of aluminum and copper are connected for this purpose by welding. This is technologically challenging, as the resulting weld seam is more brittle the more that the dissimilar metals mix, as is unavoidably the case in conventional laser welding. Brittle weld seams – without a doubt – are simply unacceptable given the advanced requirements of electromobility.

In the previously mentioned process steps in battery production – the welding of electrical conductors and boxes – lasers are already being used today. But up until now this has always been in the form of expensive multimode systems in the range of up to 6kW, which are run with high process speeds. Why? So that the molten bath will harden quickly and the mixing of materials that is so critical for the quality of the seam will be kept as low as possible. In addition to the immense costs for the beam source and the beam guide, this results in a very unwieldy and virtually uncontrollable process with low stability and a very small process window.

But the time for this expensive hardware, with its less than convincing results, now belongs to the past: the interdisciplinary laser team at Manz AG has brought to industrial maturity a new welding process where the mixing of melts is almost entirely eliminated: laser welding in overlap configuration via high-frequency local modulation, or "wobbling". With wobbling, the depth and width of weld seams are configured independently of each other in the micrometer range. This secures flexibility in the application that is just what is needed in welding bimetallic connections, gas-tight battery boxes, but also for highly reflective copper materials. Seams produced in this way have a very high resistance without brittle intermetallic phases. The connection cross-section can range from a few tenths of a millimeter to a square millimeter for each millimeter of seam length, even with a low sheet thickness. The newly developed high frequency modulated overlap welding method also has a beam source with a power output up to 80 percent lower.

Stable, precise, flexible with new scanner

The new process is a "sensitive" welding process. It is one where the weld penetration depth can be kept constant down to the micrometer while simultaneously reducing material inclusions. And it also pays for itself much more quickly. Weld seams with very low-porosity, or spot welds with virtually any aspect ratio, and even weld seams with square cross-sections, are no longer an obstacle. In addition to the previously known parameters for adapting the laser welding process, there are three additional parameters that bring enormous increases in flexibility.

- the geometry
- the amplitude *a*
- the frequency *f*

The geometry describes the micropath that the laser forms on the workpiece. Circles or figures of eight are possible, for

What were the challenges for the developer team?

- Overlap welding
- No full-fusion welding
- Sufficient seam cross-section area (cross-section area of terminals at a minimum)
- Low contact resistance
- High resistance and ductility
- No brittleness of the seam from intermetallic phases
- High thermal shock resistance
- Significant cost reduction in laser system technology the process window.

example. The amplitude expresses the half width orthogonally to the feed direction of the laser micropath on the workpiece. The frequency indicates how many instances of the wobble geometry are produced per second. The overlap of the individual circles is a result of the geometry, amplitude, frequency, and feed speed.

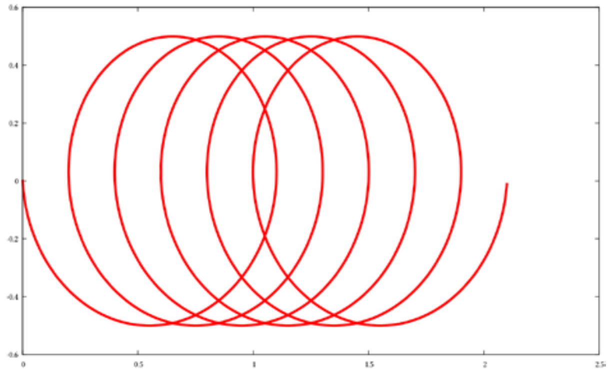

Image 1: Example of a circle-shaped wobble geometry with 0.5 mm amplitude

To satisfy the requirements for the dynamics of this type of process control, a new 2-axis scanner system has been developed which is significantly superior to previous systems in terms of dynamics, stability, and precision. With this system a wobble frequency in continuous operation of up to 4 kHz can easily be achieved. An additional challenge with the current scanner systems is the calibration of the scanning field. For this purpose a calibration method has been developed by Manz for this and other scanner applications (also 3D) that runs fully automatically and can be used even by a novice.

By using highly brilliant beam sources from the latest generation it is possible to achieve intensity levels that are significantly higher than with conventional laser beam welding, even with a fraction of the laser output.

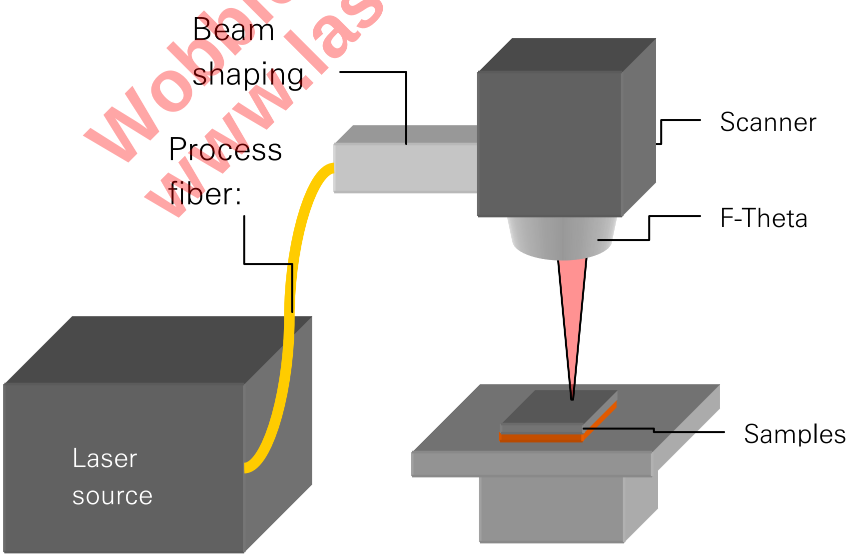

Image 2: Structure of the newly developed process for high frequency modulated overlap laser welding

Tensile weld seams even with low output

What were the results of the first tests with the new wobble welding? With a tensile testing machine, the wobbled bimetallic weld seams were tested for tensile strength. During these tests it became clear that the results for aluminum-copper welds remained relatively constant over a rather wide output range of approx. ±15 percent of the average laser output. This suggests a robust process in terms of the laser output used. The resistance values of the copper-aluminum welds by contrast fell by up to 10N/mm, even at the maximum value. In addition, fluctuations in the laser output had a strong influence on the resistance of the seam, which suggests significantly lower process stability. Based on these results, aluminum-copper welding clearly has the edge.

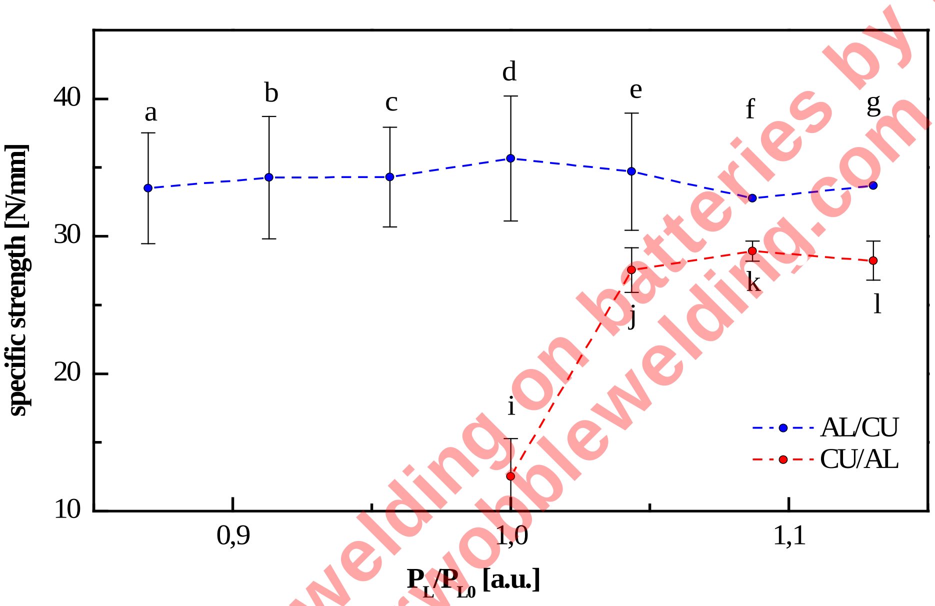

Image 3: Specific tensile strength of samples as a function of laser output being used.

For these tests the length of the weld seams was 20 millimeters. To determine the specific weld seam stability, the absolute resistance of the weld seam was applied to the seam length of 20 millimeters.

Micrographs indicate a lack of mixing

When aluminum and copper mix together, this results in brittle intermetallic phases which have a negative effect on mechanical resistance as well as the thermal shock resistance. To understand how these two properties have an influence with both aluminum-copper and copper-aluminum weld seams, the developer team produced micrographs of such seams and evaluated them using optical miscroscopy and energy-dispersive X-ray spectroscopy (EDX). Using these micrographs, it is possible to draw clear conclusions concerning resistance as a function of the degree of mixing. The parameter with the greatest resistance according to the polynomial fit (Al/Cu) is P_0 and is thus significantly lower than 500W. However, this is also the parameter for which an increasing mixture of aluminum and copper is observed. For simple tensile tests without previous temperature change load, this is less of a problem. Even the parameter with just 86 percent of the laser output of P_0, with approx. 34N/mm of specific tensile strength, still shows an astonishingly high level of resistance, although the connection area is only located on the surface of the lower copper sheet. Therefore a minimal weld, i.e. the soldering of the top aluminum sheet to the surface of the copper sheet, is sufficient to achieve a high tensile strength. The chance of brittleness forming is thus completely eliminated with this connection.

Image 4: Detailed photo of the connection point from image a.

It can also clearly be seen that even the maximum 5 micrometer thick nickel layer that is supposed to protect the copper sheet from corrosion was only minimally affected. This can be seen particularly well using EDX photographs, which can be seen in image 5 with selected Al/Cu welds as examples.

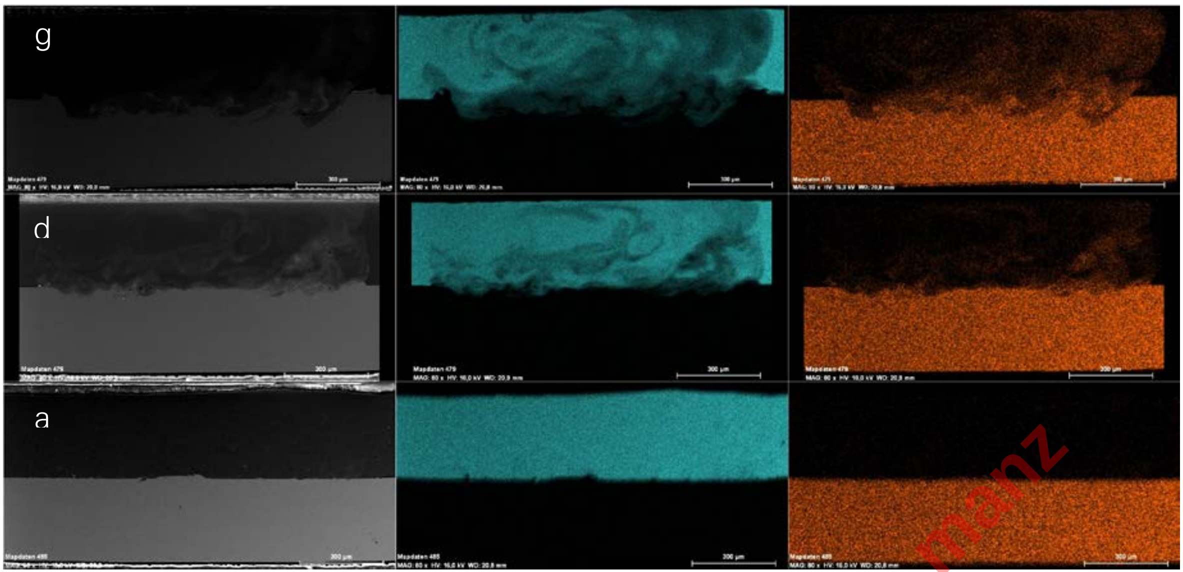

Image 5: Selected EDX photographs of Al/Cu welds (left: scanning electron microscope photograph, center: EDX mapping aluminum, right: EDX mapping of copper.

The results are different with the copper-aluminum welds. These show the highest level of resistance at approx. 110 percent of P_0 (see image k). A clear mixing of aluminum and copper and a marked formation of pores on the weld seam root can be observed. With a slightly lower or greater mixing (Image.i/l), the tensile strength of the connection falls relatively quickly. In addition, it is not possible to produce a connection that is mostly free of mixing, as in Image.a, with virtually comparable resistance levels. To achieve a particular resistance, a mixing of aluminum and copper appears to be necessary.

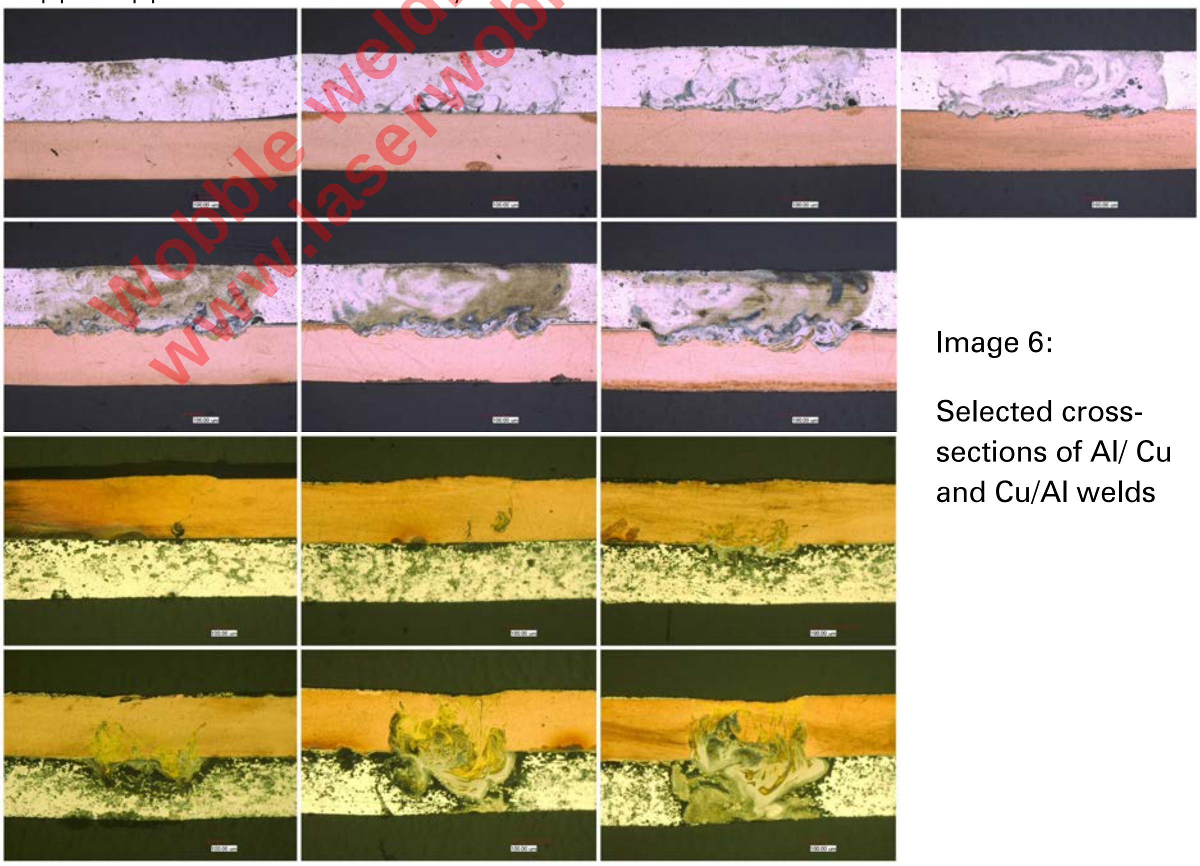

Image 6:

Selected cross-sections of Al/ Cu and Cu/Al welds

To test the thermal shock resistance of the weld connection as a function of the material mixing, 3 sets of parameters of both the copper-aluminum (Image.j,k,l) and the aluminum-copper welds (Image.a,d,g) underwent a temperature shock treatment in accordance with the standard DIN EN 60068-2-14Na. Here the weld seams had to withstand 300 cycles between -40°C and 130°C in two weeks – over 30 minutes with a maximum transfer period of 30 seconds. The tested weld seam length was 20 millimeters, and stress concentration was eliminated in the test setup. The results, both internally and externally, have shown that a temperature shock load of this type has no effect on the resistance of the weld connection.

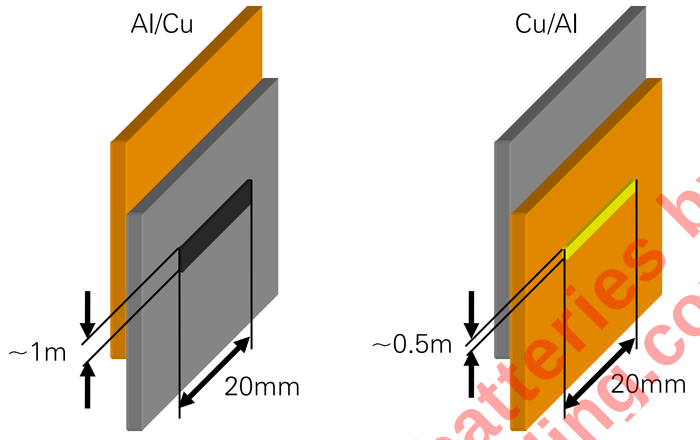

Image 7: Samples and weld seam geometry for the temperature shock test and also the tensile tests.

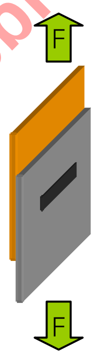

Image 8: Load direction of samples in tensile test.

Welding much more than bimetals

In addition to the welding of bimetallic connections, high-frequency modulated overlap welding is also well suited for critical welds within the battery cell itself, for example for connecting the positive (Al/Al) and the negative pole (Cu/Cu). If the battery cells are "wired", they are connected to battery packs, as mentioned above. The manufacturers of Li-Ion batteries, in coordination with their customers, the automakers, currently rely on three possible geometries. The new

overlap laser welding method can be used with all three. Pouch cells, which resemble thermal packs, are connected with bimetallic contacts in series. With a process speed between 60 and 100 mm/s, the new process is both very cost-effective and can also be used to generate large current-carrying cross-sectional areas with minimal investments.

Both prismatic and cylindrical hard case cells primarily consist of gas-tight welded aluminum boxes. They must be able to withstand a bursting pressure of over 40 bar and also be helium-tight until below the detection limit. Wobbling provides very homogeneous weld seams, both from a functional and an aesthetic point of view, when welding the battery cover to the box, with excellent weld beads. An important advantage here is the excellent flexibility: the parameters of the weld seam geometry can be freely selected, e.g. widths from 0.1 to 1 millimeter and more are easily possible. Two-dimensional weld seams can also be created, e.g. in order to connect the negative (Cu/Cu) and positive (Al/Al) pole to the box and the contacts attached to it. Here the wobble method succeeds because of the minimal required weld penetration depth with a simultaneously large connection cross-section.

The new weld method can be used with the same beam source and beam guide for all these application scenarios, i.e. geometries of Li-ion batteries. Bimetals, aluminum, copper or steel: no problem. All required parameters can be set for the relevant task. Even spot welds are possible, with up to 3,500 welds per second.
Of interest to users: Existing production lines can be refit with the newly developed hardware.

How was the high frequency modulated overlap welding method tested?

To qualify the new welding process for connecting aluminum and copper terminals, a parameter study was conducted with internal tensile tests on an improvised test stand. After calculating the suitable parameters, a relatively wide parameter range was examined using micrographs and three characteristic parameter sets were selected for each material pairing (Al/Cu and Cu/Al). These were then examined in detail and tested using REM photographs, EDX mapping, temperature shock testing, and external tensile tests. The results show that with aluminum-copper connections a maximum tensile strength of 0.726kN or 36N/mm was reached. The temperature shock test has no measurable influence on the seam resistance, provided the mixing of aluminum and copper can be minimized. By contrast, the copper-aluminum connections have a resistance of just 0.647kN or 32N/mm. With this material combination, it is significantly more difficult to minimize the mixing, which is due among other things to the considerable differences in melting point between aluminum and copper. This fact benefits the aluminum-copper connection on the other hand and enlarges the process window.