Whitepaper

Laser applications for structural components of EV battery pack

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Abstract

This whitepaper aims at providing guidelines to select laser welding and cleaning equipment as well as process control in the context of battery box manufacturing for battery electric vehicles (BEV) in mass production. The battery box, as an integral part of the chassis of BEV, not only protects the battery and BMS, but also keeps the vehicle and its passengers safe from battery leakage, fumes, and fire; especially during a crash. For BEV makers, about 10 to 20 percent of the total cost of a finished lithium-ion battery pack comes from the pack stage production. Pack manufacturing costs plays an important role in electrical vehicles' total price. On the other side, lightweight and safety consideration with extra structural reinforcement are essential factors in designing and manufacturing the battery box, which can be made of either aluminum alloys or advanced high strength steel (AHSS). Typically, a total ~30m of weld length is necessary during the construction of a battery tray to join the lower shield plate to the side/cross members, and brackets to BIW with gas/water tightness. This underscores the need for a robust and productive weld solution with good gap bridging. To meet stringent cost, lightweight, and safety requirements, laser is a key enabling technology for battery pack structural parts using either aluminum alloy or advanced high strength steel.

Battery pack structural parts and laser application overview

Selection of materials, structural design and joining process is a balance between technical performances (strength, weight, sealing) and cost for battery box manufacturing. Aluminum alloy and steels are both used in high volume production, whereas composite can be found in low volume, low range battery vehicles.

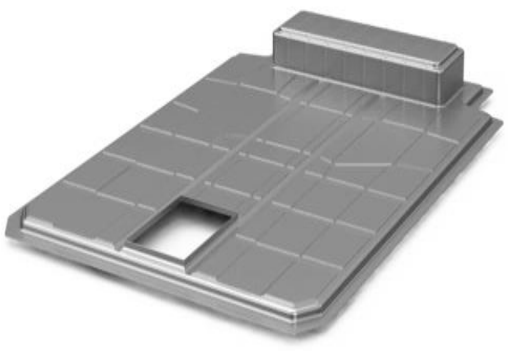

Figure 1: Top cover plate
The top cover plate encloses the pack with good sealing and electromagnetic combability (EMC). The component can be brought into its final form with laser cutting, edge-forming, punching, and bending processes. Cathodic dip paint is removed to ensure safe sealing and EMC.

Figure 2: Tray
The battery tray encloses protective housing for the battery pack, electronics, and cooling unit. TRUMPF machine systems process flat sheet metal by laser cutting, bending, punching dies, and laser welding to create a gas-tight battery tray – depending on the requirements.

Figure 3: Frames
The frames are normally made of profiles to support high loads from impacts and dissipate the energy. Crash-optimized designs of flangeless connections can be implemented with the TRUMPF machine portfolio.

Figure 4: Segmentation and cross member
Cross members mitigate deformation during crash impact. A stable frame is used to position the battery module in the battery tray. TRUMPF offers a wide spectrum of solutions for many joining tasks, such as remote laser welding with beam shaping and beam oscillation, or welding with filler wire.

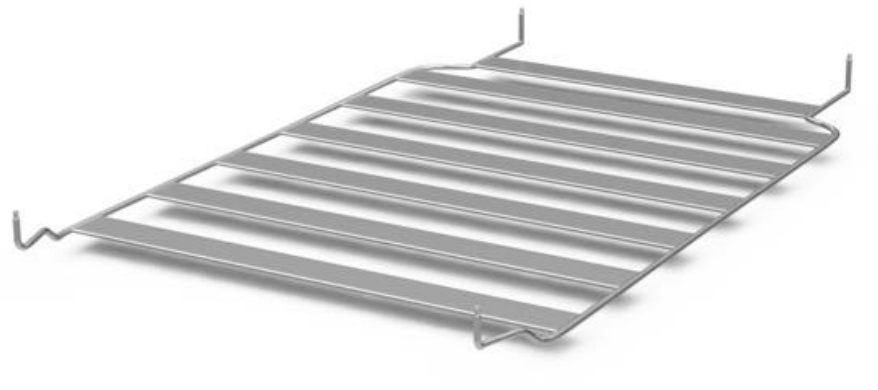

Figure 5: Cooling system
The cooling system provides optimum operating temperature range. Whether plate heat exchangers, pipes, or punch press profiles. TRUMPF offers the suitable production system for every design and material.

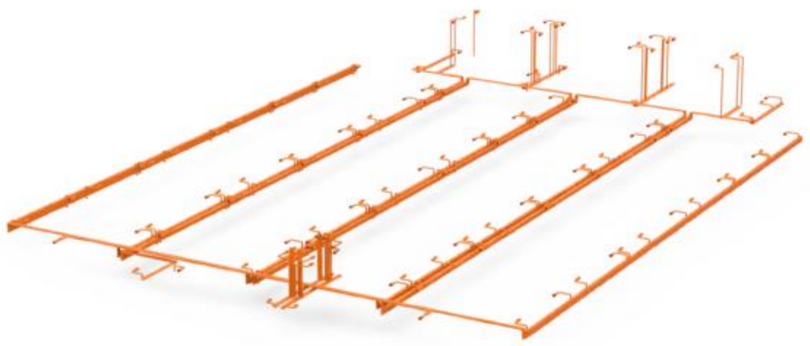

Figure 6: Signal and power connections
Live connections such as busbars and copper connectors are welded energy-efficiently using a laser. Processing times and spatter formation are minimized with BrightLine weld and TRUMPF weld depth monitoring. Marking lasers are used for clear and permanent component marking.

Figure 6: Lower shield and reinforcement
The lower shield prevents damages to battery pack from road debris. Reinforcement is normally required to mitigate deformation in the event of a crash. Remote laser welding is used to weld reinforcement to lower shields.

Remote laser welding with BrightLine

Remote laser welding (RLW) is well established as the automotive industry's number one choice for joining processes. Welding process takes place without moving the workpiece or the focusing optics. This greatly improves productivity and process flexibility, making RLW a preferred solution for welding cross members, lower shields and battery trays. With RLW, customized weld patterns with different shapes, orientation, and distribution can be realized, which is necessary for joint strength and stress optimization on battery box structural parts joining.

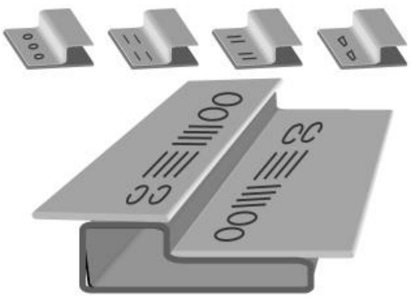

Figure 9: Customized weld pattern with RLW

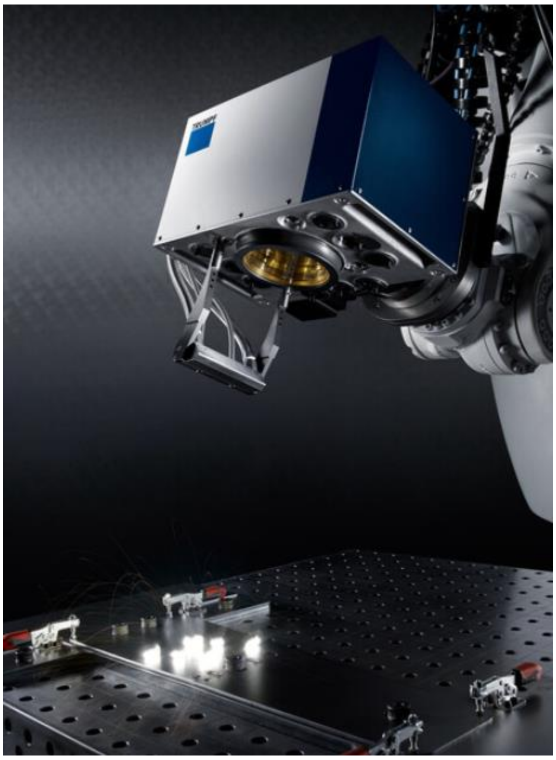

Figure 8: Remote laser welding

Beam shaping with BrightLine Weld

TRUMPF's BrightLine weld technology is essentially a beam shaping method. It is realized through the patented 2-in-1 fiber, which is made of the inner core fiber and outer ring fiber. Laser power is able to be distributed freely between the inner core and outer ring, thus to create a superimposed two beams into one process zone, as illustrated in figure 10.

During deep penetration process, part of the metal is vaporized and creates a pressured vapor at the bottom of the keyhole. The vapor accelerates melt pool upwards and excessive acceleration causes loss of the material, which is, spatter. In the case of BrightLine weld, the additional ring beam creates a larger keyhole opening to allow metal vapor to escape. This also helps to create a more stable keyhole to avoid keyhole collapse, thus avoiding large pores formation.

At the same time, the additional ring beam changes the dynamics of the melt pool. The metal melt, which is accelerated to the surface direction, receives an opposing impulse through the ring beam and deflected to the side.

As a result, with the combined effect on keyhole and melt pool dynamics by introducing a superimposed ring beam, it is shown in test that up to 90% of the spatter can be reduced.

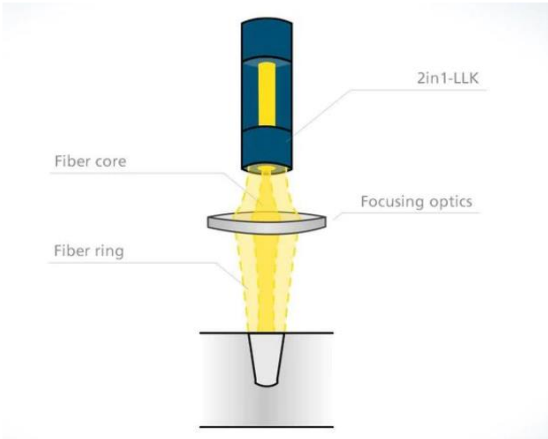

Figure 1: BrightLine Weld beam shaping

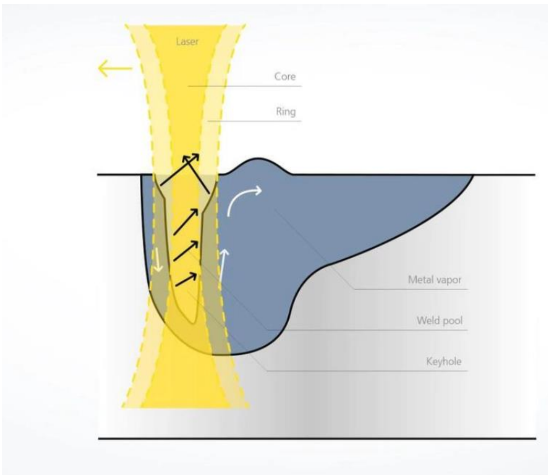

Figure 2: Spatter reduction with BrightLine Weld

Beam oscillation

Figure 11:
Illustration of beam oscillation

One drawback of RLW is it cannot weld across gaps in butt joint seams as there is no way of adding filler material. The new wobble method overcomes this problem, in that the laser beam doesn't just move along the gap in a straight line, it oscillates from side to side. Moving the beam in a spiral motion melts material to the left and right of the gap and broadens the melt pool. The liquid metal replaces additional filler materials like welding wire, and bridges even larger gaps.
Laser beam oscillation with a high brightness, high intensity laser beam, opens up new possibilities of improving the welding process in terms of compensation of larger tolerances, reduction of porosity, increased aesthetics of weld seam and process stability. In some cases, autogenous welding of materials that normally require filler wire is possible with oscillation welding. The combination of beam shaping and beam oscillation with autogenous RLW joining process is an effective solution to improve keyhole stability and maximize weldability of aluminum alloys and some AHSS. Marco cracks can be effectively avoided by the use of fillet lap joint configuration, shown in the picture below. However, random micro cracks are still found with certain materials. Fig 12-14 below shows welding result comparison with beam shaping only, oscillation only, beam shaping and oscillation combined on 6xxx series aluminum.

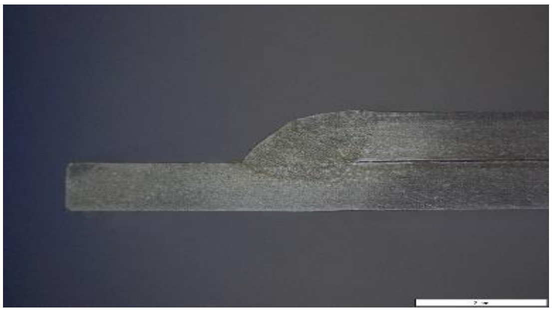

Figure 12:
Beam shaping

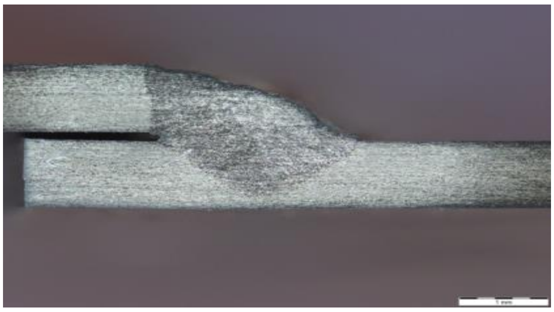

Figure 13:
Beam oscillation

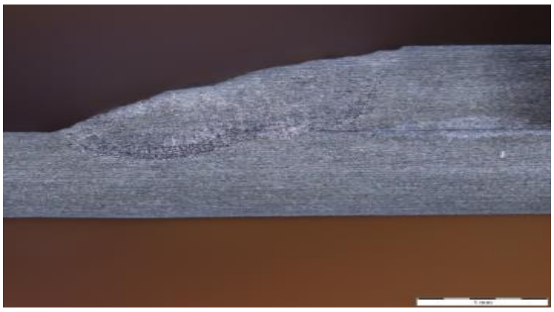

Figure 14:
Beam shaping and oscillation

Laser welding with filler wire

Autogenous laser welding is preferred in automotive manufacturing. However, certain high alloy materials and difficult applications require the use of filler material in the battery box welding process, including but not limited to the following reasons:

Weld porosity – pores which are trapped in the melting pool reduce weld strength, durability and water/gas tightness;

Part fit-up – manufacturing tolerances of extruded profiles or stamped AHSS with large spring-back may lead to poor part fit-up.

Micro cracks – Although macro cracks are greatly mitigated by combination of beam shaping and oscillation, micro crack sometimes still present for some alloys because of high thermal stresses during solidification.

Laser welding with filler wire is a multi-parameters process, weld quality is affected by laser beam and filler wire interaction, in which the wire feed speed and angle is critical for a successful welding

TRUMPF has put its experience in laser welding with filler wire in the so called “FusionLine” technology with its TruLaser Weld system. Both weld and filler wire parameters were developed and optimized to produce good quality welds without cracking or porosity, with correct weld geometry, and closes gaps up to 1 mm wide.

Laser welding with filler wire is able to deliver crack-free weld and bridge larger part-to-part gap. However, it also increases system complexity, reducing welding speed, and adding more consumables cost.

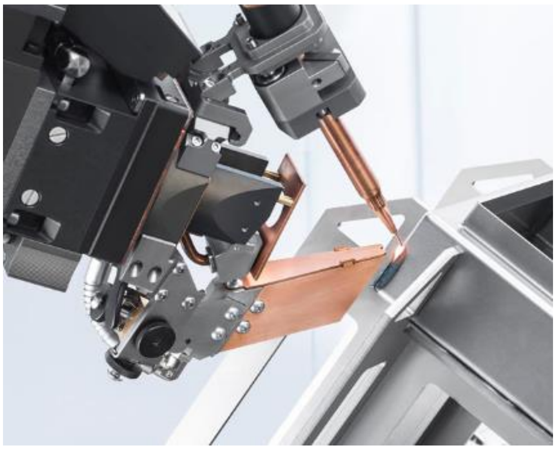

Figure 15: Laser welding with filler wire

Figure 16: TruLaser Weld 5000 system

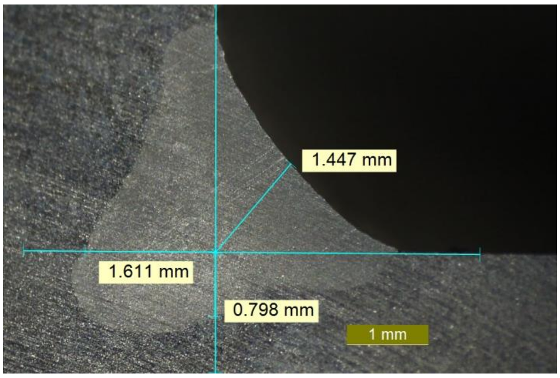

Figure 17: Laser welding cross section with filler wire

Hybrid laser welding

Figure 18: Hybrid laser solution with TRUMPF laser and optics integrated

Hybrid laser welding refers to processes in which laser welding is combined with other arc welding methods. The arc acts on the surface and provides a broader seam and bridge gaps. The laser delivers the high power densities needed for the deep welds and enables high welding speeds. This, in turn, reduces heat input and distortion. In terms of welding challenging materials, such as 6000 series Aluminum alloy and AHSS that are widely used in battery box structural parts, hybrid welding has flexible control of heat input into material. It gives the user the option to optimize heat input and cooling rate by adjusting laser and MIG/MAG torch parameters, to avoid overly weakening or hardening the fusion area. The use of filler wire does not only bridge gap but also gives the welder a direct influence on metallurgical properties, to get rid of micro cracks and improve weld toughness. As a result, hybrid laser welding is well suited for long seam welding on relatively thicker and high strength structural components, such as cross member and frames, which requires deep penetration and good gap bridging capabilities. However, the increasing mechanical complexity of combining two process remains a challenge. The interaction between laser and arc requires a deep understanding of both process to optimize relative setting of several process parameters. TRUMPF has partnered with several premier arc welding suppliers to provide hybrid laser welding solutions for over 20 years. We are able to support you to meet the challenges in hybrid welding of battery box parts.

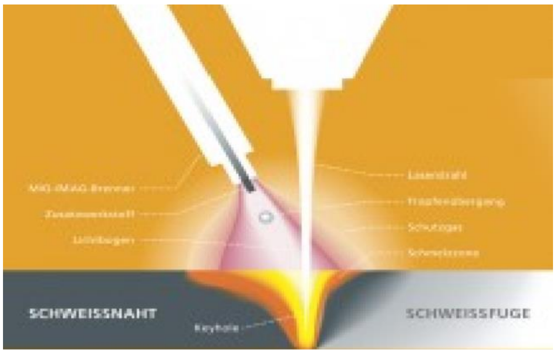

Figure 19: Hybrid laser welding schematics

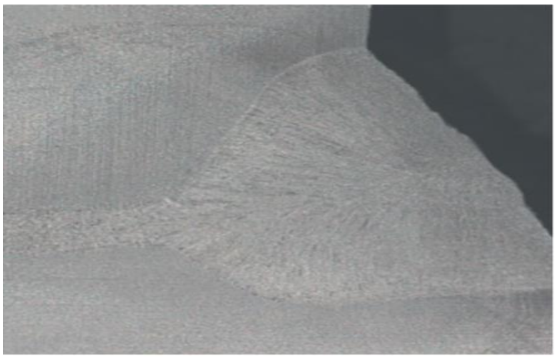

Figure 18: A typical hybrid laser welding cross section

Laser cleaning and ablation

Welding and adhesive bonding require clean surfaces free of debris, oils, and corrosion. Cleaning the surface prior to the welding or gluing process is critical to maintain battery box welding quality and gas/water tight sealing. In addition to that, cathodic dip paint (CDP/KTL) on battery box frames and cover plates must be removed for electromagnetic compatibility (EMC).

A typical laser cleaning system used in battery box application consists of a nanosecond pulsed laser combined with scanning optics. The scanner makes closed contour movement in endless loop and it is synchronized with robot movement. Depending on robot movement direction, the scanner movement can either be programmed as linear lines or circular movement.

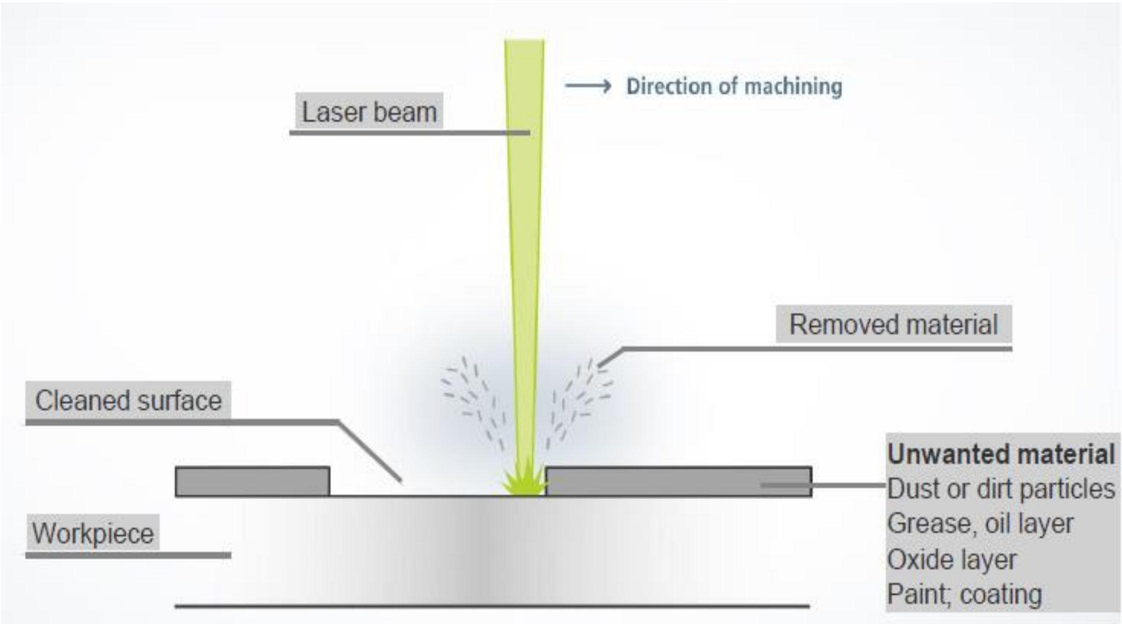

Figure 21:
Laser cleaning principle

In figure 22, a high power short pulsed laser system with PFO scanner optics mounted on a robot is used to remove CDP coating on battery box cover plate. In this fully automated process, CDP coating ablation rate of 30cm^2/s is possible.

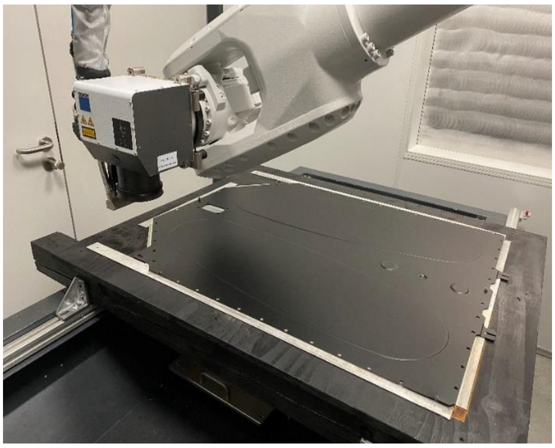

Figure 22:
Laser ablation of CDP painting

+ Contactless
+ Precise and selective cleaning
+ Repeatable process
+ No substrate damage
+ No rinsing and drying afterwards
+ No waste to sort afterwards
+ No repair or replacement of the tools
+ Consumable-free
+ No chemicals
+ No abrasive cleaning

Figure 23:
Benefits of laser cleaning and ablation

Beam tracking, weld depth monitoring, and weld seam inspection

In battery box mass production, the welding quality can be disturbed by various factors such as the internal defects of materials or the complex manufacturing environment. To monitor and ensure welding quality, EV manufactures prefer to use in-line monitoring instead of traditional off-line testing methods due to time, material cost, and productivity considerations.

State-of-the-art real-time and direct weld quality measurement of the keyhole depth is optical coherence tomography (OCT), and it has been successfully used in automotive manufacturing including battery box production.

With OCT, light reflections are measured by the Michelson interferometer, using the low coherence properties of a broadband laser source. By comparing the travel lengths of the reflections of the measurement laser beam directed towards the keyhole bottom with that of a reference laser beam inside the interferometer. Any change in the keyhole wall or depth will generate interference fringes, which are translated into distance measurement.

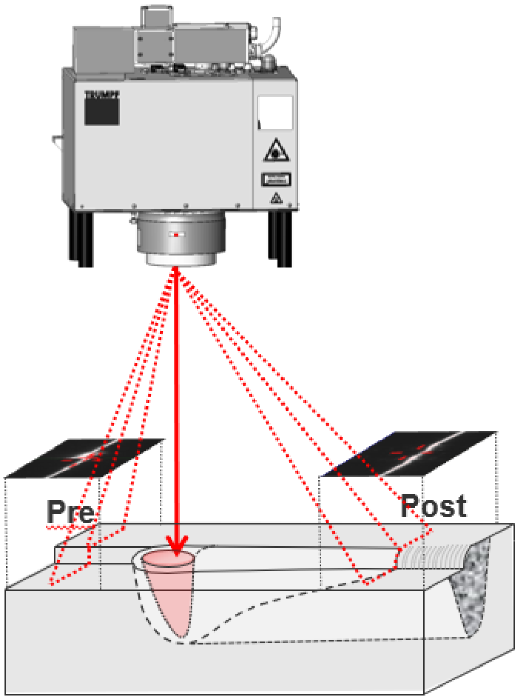

Figure 23:
Sample text in 9pt
Pre-, In- and Post-monitoring

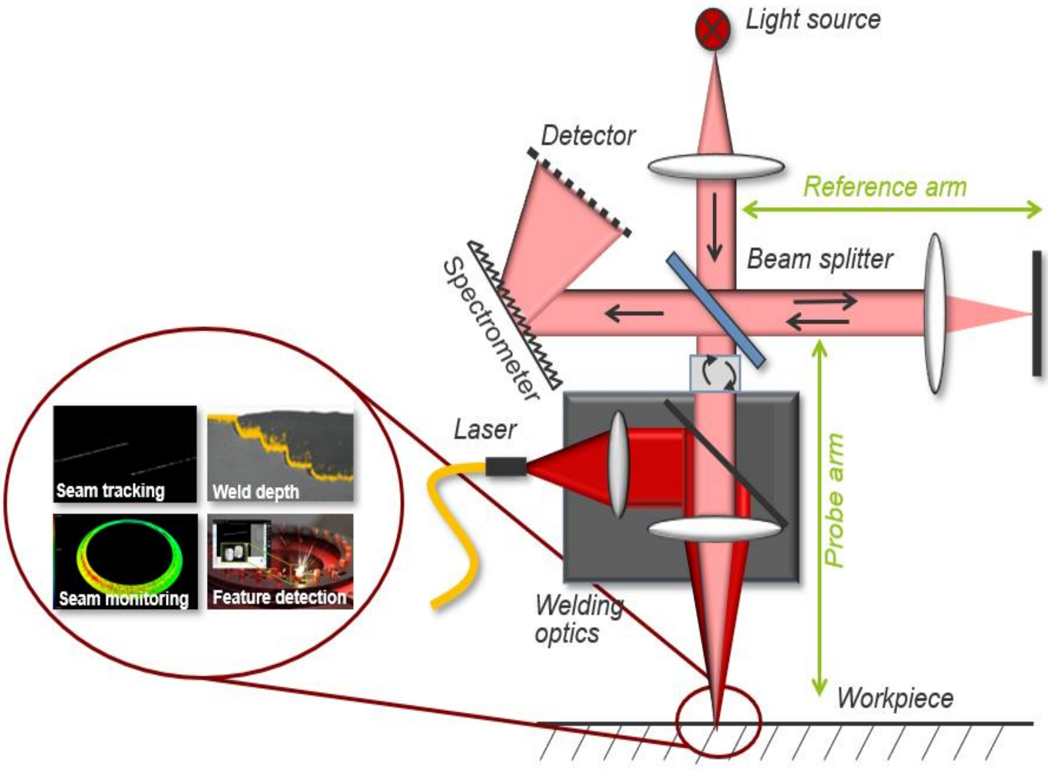

Figure 24:
Work principle of optical coherence tomography

The monitoring process can be divided into three different parts: the pre-processing scanning, the in-process monitoring, and the post-process diagnosing. The different stages of welding monitoring are shown Fig 21.

The **pre-process** scanning mainly focuses on the seam tracking, scanning the joint edge gap between workpieces to ensure that the laser beam is on track, independent from part to part variance.

The **in-process** monitoring pays close attention to the real-time monitoring of welding characteristics in the welding zone such as keyhole. When the OCT measurement beam is correctly aligned towards the keyhole, the OCT technology is capable of providing fast and accurate direct measurement of the keyhole depth.

The **post-measurement** can be used for weld quality assessment. The pore, crack, spatters, surface collapse, underfill, etc., are the common defects; which are the critical indicators in the quality evaluation of weld seam.

TRUMPF has integrated the OCT sensor into its VisionLine system to allow quick setup and intuitive operation. The operator is able to see and actual part through the camera. Both the camera image and OCT signal are integrated in the same software interface, this allows the operator easily and accurately align the OCT beam to the exact position to measure the desired 3D features.

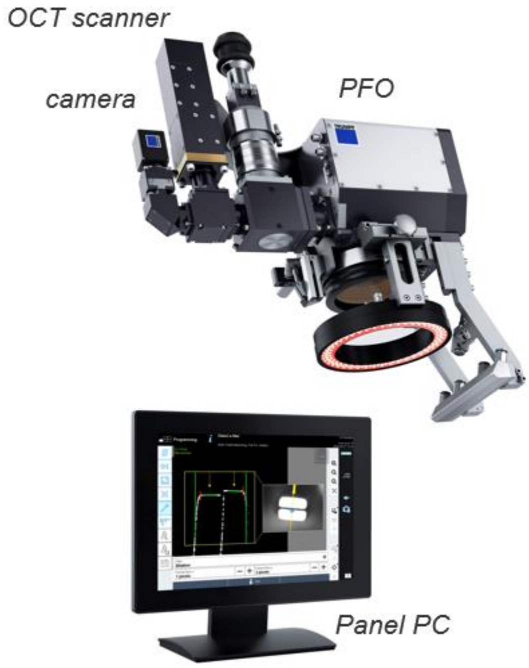

Figure 25:
Integrated OCT sensor with camera system

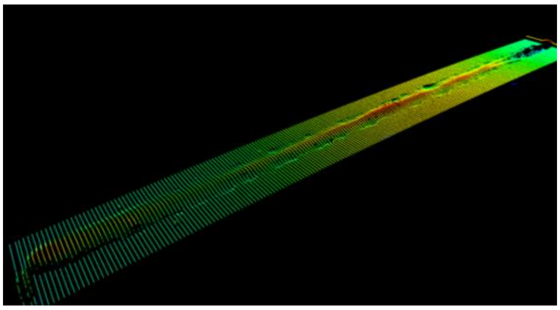

Figure 26:
Post-measurement of weld seam profile

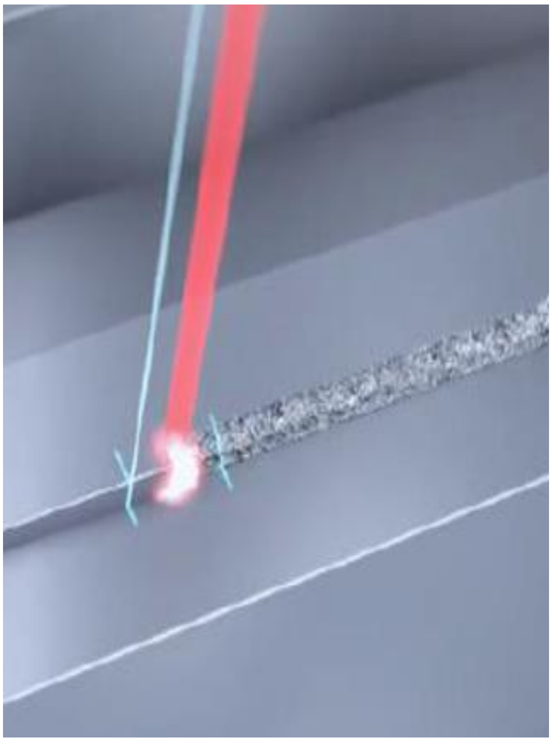

Figure 2:
OCT sensor for seam tracking and seam inspection

Conclusion

Laser welding has been proven to be an effective solution for battery box manufacturing to achieve optimal cost, quality, and productivity.

Remote laser welding, combined with beam shaping and beam oscillation, is an effective solution to improve keyhole stability, reduce spatter, bridge gap, and maximize weldability for most of the materials commonly used as structure components in battery pack.

Tactile Laser Welding (TLW), with the use of filler wire, brings benefits such as reduced heat input and single side access, and is able to effectively join materials that require chemical alteration to achieve crack free welding and large gap bridging. Both RLW and TLW find plenty of opportunities in welding battery box components such as frames, cross-members, bottom reinforcement, as well as brackets to BIW.

In addition to laser welding, laser cleaning is able to generate controllable and accurate removal area with minimal damage to substrate, thus it is an ideal method to remove cathodic dip paint cataphoretic paint, as well as pretreatment for welding or sealing surface on top cover or frames. In addition to laser welding, laser cleaning is able to generate controllable and accurate removal area with minimal damage to substrate. Therefore, it is an ideal method to remove cathodic dip paint, cataphoretic paint, as well as pre-treatment for welding or sealing surface on top cover or frames.

For battery box joining process control and quality monitoring, OCT technology provides real-time and direct measurement for seam tracking, weld depth monitoring as well as weld seam inspection. Quick setup and intuitive operation is realized by integrating the OCT sensor with VisionLine camera system.

Click here for more information

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