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High-speed welding in EV industry with next-gen laser sources delivering superimposed beams

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Abstract

Over the last years laser welding with superimposed beams has lifted the welding performance in terms of speed and quality on a new level. However, the use of a superimposing ring beam increases the overall spot size on the surface of the material to be welded, which can be critical in some welding tasks, such as welding of thin metal foils. Therefore, a new laser source with increased brilliance and very small ring spots, covering the main spot, has been developed and applied for welding tasks from electric vehicle industries. It is shown that the welding speed and process stability can be increased with this new approach and a big scanning field at the same time can be achieved.

Keywords: Welding, battery, busbar, hairpin, bipolar plates, E-Mobility

1. Introduction

The electric vehicle (EV) industry is one of the fastest changing and most disruptive industries, laser and system technology manufacturers are facing since a couple of years. The transformation to battery driven cars means scaling up completely new processes to large scales in short time. The laser has been proven to be the key tool for the successful transformation over many times. Scaling up battery cell manufacturing requires reliable processes within short time and a high degree of automation. That´s why many (scanner-) based laser welding applications have found their place in the gigafactories of different cell manufacturers worldwide.

2. Welding with Superimposed Laser Beams

Different kinds of battery cell contacts, mostly made of aluminum, copper and steel, require low spattering, no pores, low heat input and accurate penetration depth. Same requirements are given the other EV industry segments, such as for eDrives, fuel cells and power electronics. For these purposes, a deep understanding of laser-material interaction and the right tools to control the process are needed.

A well-described approach [1-4] to control the welding process by stabilizing the keyhole is the superimposition of two laser beams. First introduced by TRUMPF, the superimposition of a beam delivered by a core and a ring fiber (BrightLine Weld) showed a stabilizing effect of the keyhole and welding process for numerous applications in copper, aluminum and steel.
Figure 1 shows the beam profile of the superimposed beam of a TruDisk - BrightLine Weld laser source in the focal plane. The sketch in Figure 2 points out that the superimposed ring beam couples partially into the keyhole and therefore the keyhole shape becomes more conical. A stable keyhole and an increased amount of molten material near to the surface significantly reduces spatter and pore formation.

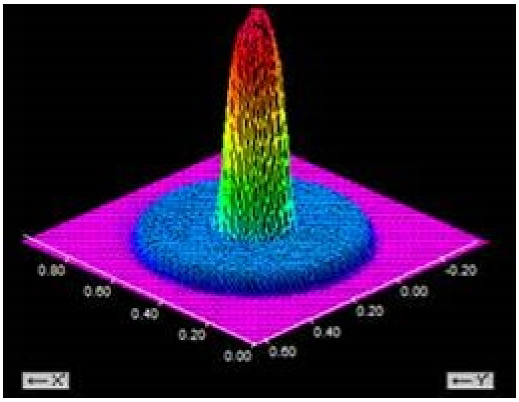

Fig. 1. Beam profile of superimposed beams

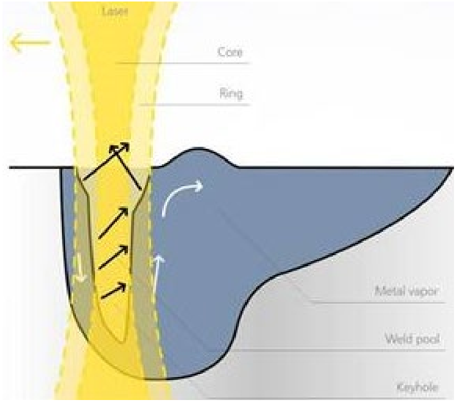

Fig. 2. Scheme of the stabilized welding process using superimposed las12er beams

While in the last few years the total laser power available has been increased up to 24 kW in combination with BrightLine Weld [4], the beam quality was kept constant at multi-mode level. However, an increased beam quality brings additional possibilities to use the tool laser with higher flexibility. Therefore, the principle of superimposed laser beams is transferred to single-mode fiber lasers. The next generation of TruFiber 6000 - BrightLine Mode combines 2 kW laser power delivered by a single-mode core fiber with additional 4 kW laser power in the Multi-Mode ring.
The experimental setup for the welding trials is shown in Figure 3 and Table 1. All welding experiments were conducted with a scanning optics PFO33-3 (Gen 3).

Fig. 3. Single-Mode laser source with additional ring beam: TruFiber 6000 P - BrightLine Mode

Table 1. Table of parameters

Parameter	Value
Laser	TruFiber 6000 p
2in1 Configuration	BrightLine Mode
Optics	PFO33-3
Focal length f	265 mm 450 mm
Power P	2 kW (SM core) 4 kW (MM ring)
Spot size on the workpiece dw	41 µm / 195 µm 71 µm / 337 µm

3. Bipolar Plates

The welding of bipolar plates (see Figure 5) for PEM fuel cells is challenging due the thin thickness of the stainless-steel sheets of 75 µm - 100 µm, the high-speed requirements and the large area that needs to be processed [5]. For one bipolar plate multiple meters of welding distance are needed. Therefore, the welding speed nowadays is usually between 500 mm/s and 700 mm/s, but should be increased of values >1 m/s. Even more important than speed only is the reliability of the weld seam. Gas tight welds are a must have to fulfill the requirements.

In order to reach this goal, two major defects must be avoided: false friends (Figure 6) and humping (Figure 7), both occurring from unstable welding conditions and both are possible causes of untight seams. False friends distinguish themselves by missing connection, although the welding appears unsuspicious from the outside. Possible causes are the deformation of the half-shells of the bipolar plates, gap and unstable process conditions. Humping is generated through regular piling up of the melt in the wake of the keyhole. Possible causes are high welding speed, large aspect ratio of penetration depth and width, fast melt flow and high cooling rates of the molten material.

Fig. 5. Bipolar Plate

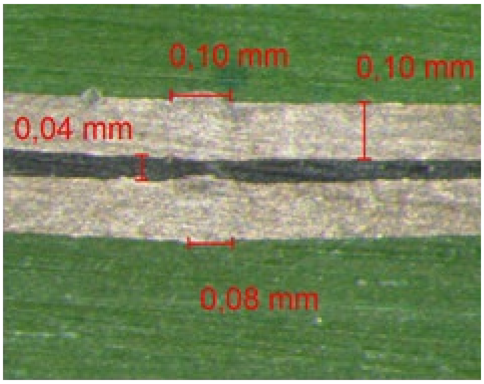

Fig. 6. False Friend

Fig. 7. Hump1ing

In order to increase the process security and speed the humping phenomena is investigated via high-speed camera observations. The process behavior is compared between a welding process applied with a cw single-mode laser with and without a superimposed ring beam.

In Figure 8 d) an image of the high-speed video of a welding process with a single mode cw laser and humping is shown. It can be seen that the molten material of the narrow weld seam solidifies in the wake of the keyhole, where molten material is accumulated and generates a hump.

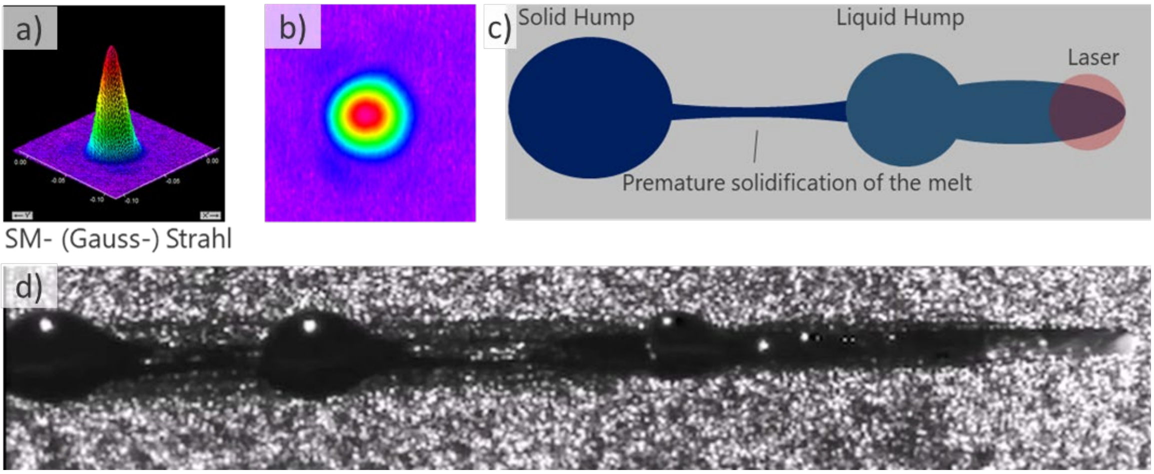

Fig. 8. Image of the high-speed video recording a welding process with humping in d), generated by welding with a single-mode laser; beam profiles are shown in a) and b), a sketch of humping generated is illustrated in c)

Figure 9 d) shows an image of the high-speed video of the welding process with a single mode cw laser a superimposed ring beam that suppresses humping. The sketch in Figure 9 c) explains the effect of lateral heating of the process zone by the ring beam. Early solidification of molten material is prohibited and no piling up of material can be seen at similar welding speeds.

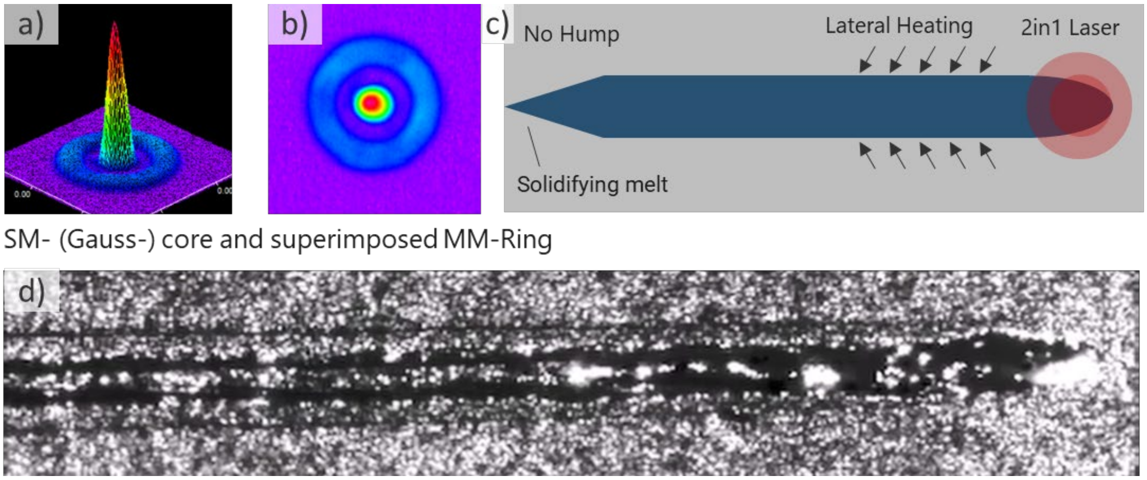

Fig. 9. Image of the high-speed video recording a welding process without humping in d), generated by welding with a single-mode laser and an additional ring beam; beam profiles are shown in a) and b), a sketch of the ring-beam effect is illustrated in c)

The values of the maximum welding speed just before humping occurs are shown in Figure 10 for different power percentages of laser power in the core fiber. It is shown that with the core fiber only (core power is 100 %), the maximum welding speed without humping is at 1000 mm/s. When applying an additional ring beam (core power is 40 %), the maximum welding speed without humping can be increased up to 1300 mm/s. Thereby, 200 µm thick stainless steel is welded through (see Figure 11).

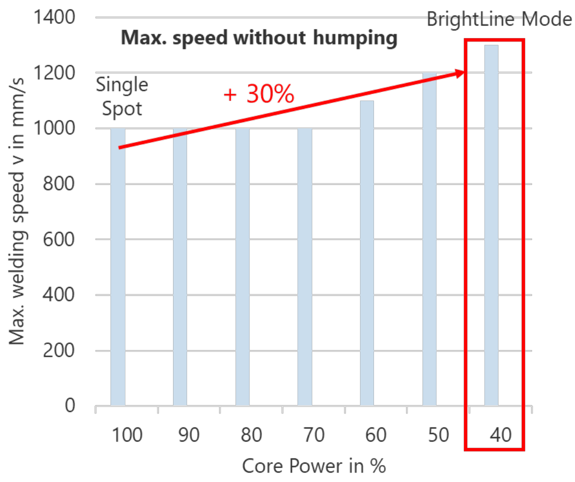

Fig. 10. Maximum welding speed without humping v is shown for different percentages of laser power in the core fiber using TruFiber BrightLine Mode, related to the total power; welded trough stainless steel with thickness of 200 µm

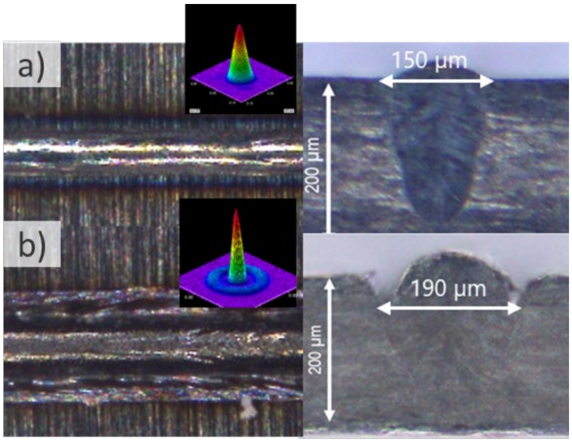

Fig. 11. Weld seam surfaces and cross sections that were generated by using a core power of 100 % is shown in detail a), and by using BrightLine Mode with a core power of 40 % in detail b)

These maximum welding speeds can further be increased for thinner material (2x75 µm in overlap), as pictured in Figure 12. It is shown that with the core fiber only (core power is 100 %), the maximum welding speed without humping is at 1400 mm/s. When applying an additional ring beam (core power is 50 %), the maximum welding speed without humping is increased up to 1600 mm/s.

Note, that these values represent only the max. speed and not the best quality welds. However, it shows that the overall process window can be increased.

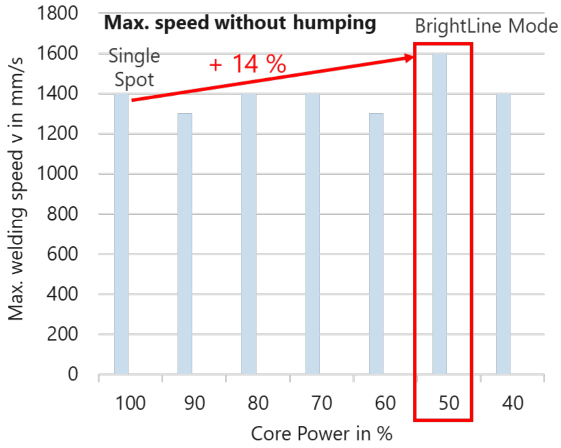

Fig. 12. Maximum welding speed without humping v is shown for different percentages of laser power in the core fiber using TruFiber BrightLine Mode, related to the total power; welded trough stainless steel with thickness of 2x75 µm in overlap

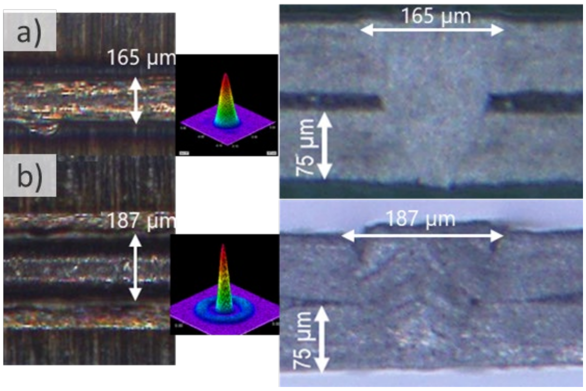

Fig. 13. Weld seam surfaces and cross sections that were generated by using a core power of 100 % is shown in detail a), and by using BrightLine Mode with a core power of 50 % in detail b)

4. Battery Busbars

The welding of battery busbars made of copper require a stable process without spattering, low heat input and constant penetration depth. As shown in Figure 14 a), the superimposed laser beams generate a stable process without spatters observed in the high-speed video and shown in Figure 14 b). The welded busbar in Figure 14 c) shows an accurate and easy controllable penetration depth, as can be seen in cross section d).

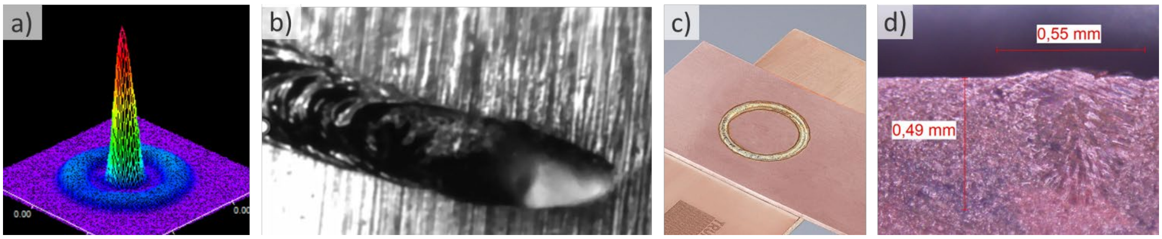

Fig. 14. Beam profile of TruFiber BrightLine Mode in a), high speed image of the welding process b) of copper busbars c) and the corresponding cross section d)

5. Hairpins

Even the welding of copper parts higher larger dimensions the welding with a single-mode laser is appropriate, if an additional ring beam is applied. The welding of hairpin stators (see Figure 15) require very short process times, low heat input and low spattering [1]. Figure 16 shows that lots of spatters are expelled from the process zone if the single-mode beam only is applied. By superimposing the ring beam, spatters can be avoided, and the process time can be reduced to < 140 ms.

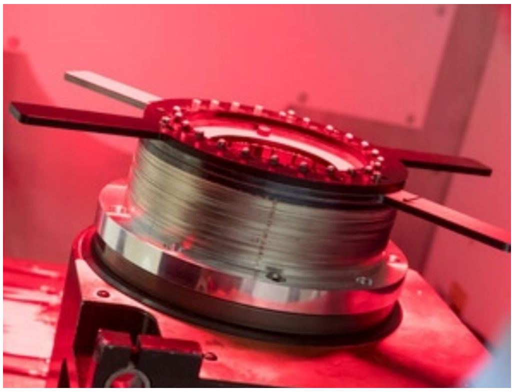

Fig. 15. Stator dummy for hairpin welding

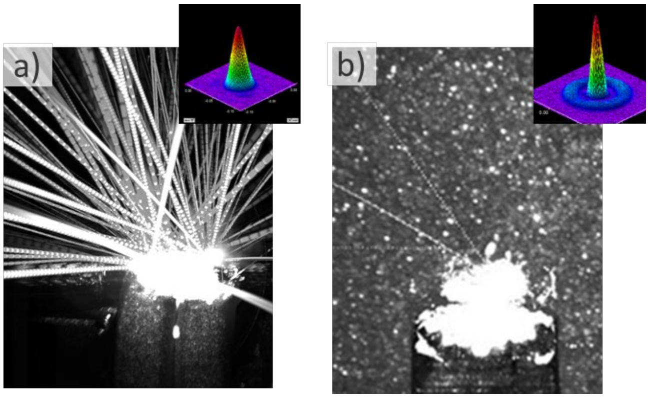

Fig. 16. Max. value images of high-speed videos, where each line represents one spatter during hairpin welding with 2 kW Single-Mode cw laser in a) and 2 kW Single-Mode cw laser with a superimposed 4 kW ring beam in b)

Figure 17 shows the comparison of different process times for different laser setups. Using Multi-Mode (MM) Laser without superimposed beams (TruDisk Core), the shortest process time all compared setups can be achieved. However, some spatters remain. By applying an additional ring beam for the MM-laser, spatters can be avoided, but the process time is more than doubled. The application of the Single-Mode Laser and a superimposed ring beam TruFiber BrightLine Mode (BLM) achieves both, small process time and reduced spatters and in addition can be applied with larger focal length in order to increase the scanning field that can be used.

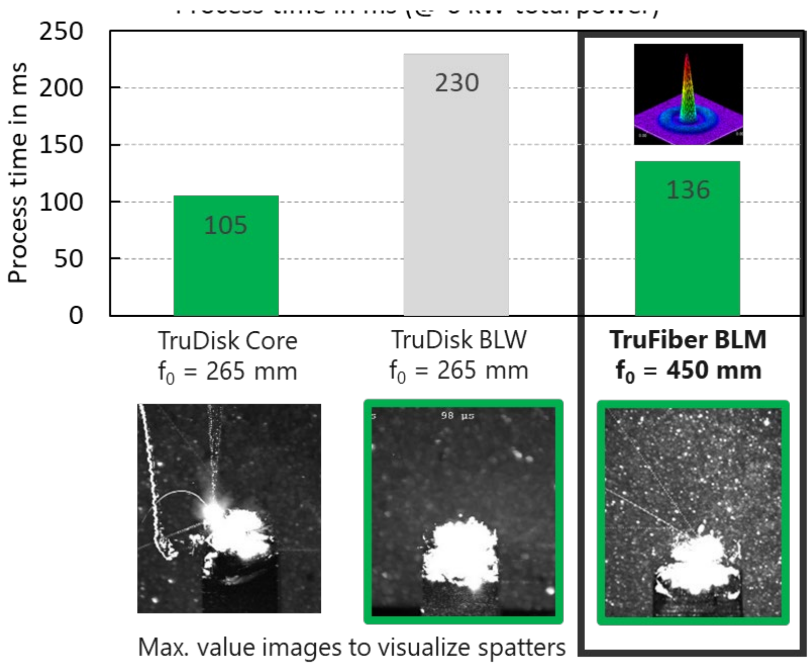

Fig. 17. Process times and corresponding max. value images compared between a welding process with a MultiMode laser TruDisk with Core and BrightLine Weld (BLW) and TruFiber BrightLine Mode (BLM)

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