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Tailored beamshape sequences for welding using a Dynamic Beam Laser

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Abstract

The industry requires high efficiency and superior quality in welding metals, particularly for complex geometries and hard-to-weld materials. In the past decades the laser has proven to be the right tool for fast and reliable welding. Especially superimposed beam oscillations in the kHz-domain enhance welding results by distributing heat over a wider area, reducing distortion and spatter. Another recent approach is to create multiple spots, lines, squares as well as intensity modulation between center and ring. Due to technological restrictions, these two common approaches are limited to rather static beamshapes. They lack the ability to be truly dynamic in the MHz-domain and therefore are unable to reach fine dynamic control over the melt pool. This paper presents the unique possibilities of coherent beam combining to create dynamic beamshape sequences for melt pool control tailored to copper and aluminum welding.

Keywords: Coherent Beam Combining, Dynamic Beam Laser, Laser Welding, Beamshaping

1. Introduction

The weld quality increase catalyzed by adjustable ring mode lasers is a great example for a successful material-tailored laser welding approach. By distributing the energy between a ring and the core inside the focus, positive impacts on spatter can be achieved [1].

Increasing the dynamics and gaining precise control of the keyhole has proven to contribute to additional reduction of spatters, minimized porosity, improved intermetallic mixing and metal structure of hard-to-weld materials like copper and other special metal alloys [2, 3].

Until now, lasers have limited the user to predefined solutions for beamshaping. Despite of laser setups that allow modulation of the energy density between the core and the ring, the beamshape remains static. The same concept applies for a diffractive optical elements (DOE). DOEs cannot be changed spontaneously during the process and therefore are unable to control the keyhole. Other solutions like galvanometric scanners are used as a dynamic aid as an alternative or in addition to DOEs. Using this solution, the dynamic range is limited to a few kilohertz [4]. Both approaches are intended to stabilize the keyhole and avoid hot cracks, porosity, and protrusions in the weld seam as well as weld spatter. In the past, dynamic processes are only combined with relatively slow laser dynamics, limiting the overall process speeds.

For unlimited control of the melt pool dynamics the only viable option are digitally controlled Dynamic Beam Lasers (DBL). The DBL offers a range of additional, variable parameters with which they can influence weld seam geometry and quality dynamically at high speeds. The stabilization of the keyhole and melt pool is very beneficial for the process. It allows control of the resulting microstructure and pushes the limits in terms of welding speeds, intermetallic mixing as well as penetration depths and widths. Typical examples are materials susceptible to hot cracking [2, 6]. For this purpose, a DBL is used to digitally define and combine arbitrary beamshapes and sequences while switching them at megahertz frequencies.

In this paper, the use of dynamic beam shaping alongside of beamshape sequences during copper and aluminum welding are investigated.

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2. Materials and Methods

The investigation is based on the 14 kW Dynamic Beam Laser by Civan Lasers Ltd. Its unique concept of high-power coherent beam combining are the foundation of the experiments. In an optical phased array configuration, arbitrary beamshapes can be created. Appending the individual beamshapes one after another creates a sequence comparable to the individual frames in a motion picture. The time each beamshape is drawn, can be set in a Range from microseconds to seconds.

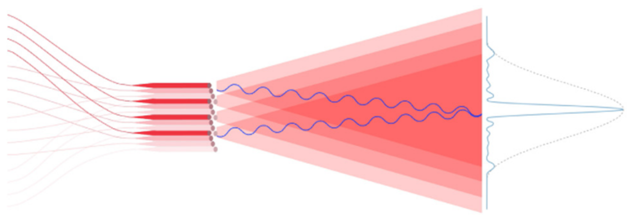

Fig. 1. Interference using an optical phased array of fibers.

The laser emits infrared light (λ = 1064 nm) with 32 individual solid-state fiber channels. Each laser channel is tuned to emit the light coherently with aligned wave fronts (see Fig.1). These in-phase beams overlap in the far field. Constructive and destructive interference creates specific light patterns. By changing individual wavefronts of the channels, it is possible to manipulate the beamshape in real time. Precisely adjusted phase shifts control the dynamic beam laser and create intensity patterns inside the focal point of the laser.

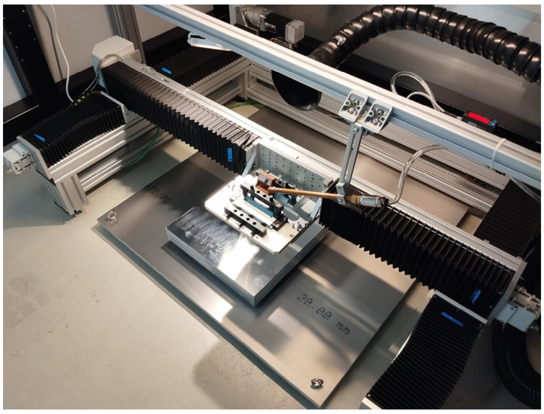

Fig. 2. Welding setup using servo controlled XY-axes.

The first set of welding experiments is carried out with 4 mm thick copper (Cu-ETP) plates in a butt-weld configuration. The workpiece is moved during the weld using an XY table with servo-controlled axis (see Fig. 2). The process zone is shielded by using Argon as a protective gas.

The laser process settings are the result of a previous process development using a statistical design of experiments (see Table 1).

The designed beamshape consists of a leading triangle with a trailing bar. The laser-drawn bar is used to induce a stirring motion into the meltpool by rotating it clockwise. During welding, the copper base material is moved below the laser beam (see Fig. 3). The focus diameter measures 650 µm. The details in the beamshape can be drawn with 60 µm resolution.

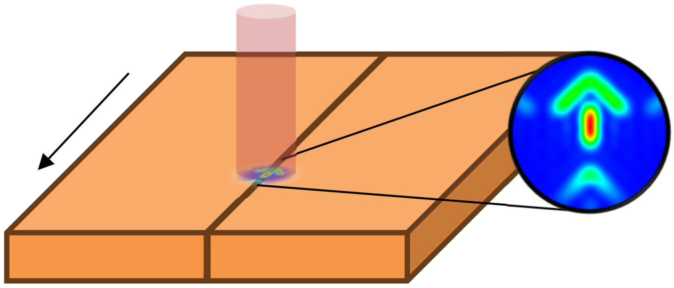

Fig. 3. Schematic drawing of the copper welding process.

The meltpool is controlled via a sequence of five individual beamshapes.

The design of the intensity distribution has two goals: On one hand, a central intensity maximum aims at increased penetration depths and a robust formation of the keyhole. On the other hand, the leading and trailing intensity combined with dynamic beam movement mitigate spatter by moving and stabilizing the keyhole.

At first, a high-intensity dot pattern is used to condition the keyhole and melt the copper workpiece as well as reaching maximum penetration. The second beamshape consists of an open triangle with a trailing stir bar pattern. Incrementally, the stir bar rotates 45° between each subsequent frame until it loops to the dot patterns and the sequence starts again (see Fig. 4). The time each shape is projected onto the workpiece in between the shapes evaluated at 10 µs and 200 µs to stimulate the meltpool movements.

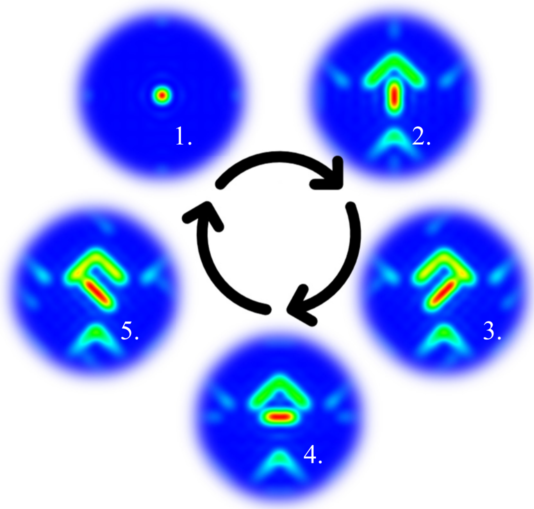

Fig. 4. Repeating beamshape sequence used for welding copper.

The same methodology applies for welds of Al 5754. These welds are carried out in an overlap configuration. Aluminium sheets with a thickness of 1 mm are welded to 2 mm substrates. In this case the development the beamshape targets to increase the interface width while maintaining crack-free and pressure-tight welds. 14 kW of laser power and a feed rate of 500 mm/s are used for high-speed welding (see Table 1).

Table 1. Laser process settings

Setting	Copper	Aluminum	Unit
Laser power	10	14	kW
Feed rate	50	500	mm/s
Argon flow	6	10	L/min
Focal length	1500	1500	mm

3. Results

The welding of the copper workpieces shows porosity and spatter when a dot static beamshape is applied. Mitigation of these issues can be reached by using the sequence designed in Fig. 4. The results show that the time between each shape in the sequence has a significant effect to the weld seam. Using 10 µs per shape, results in successful welds, but fine pores can be detected at the root of the weld (see Fig. 5).

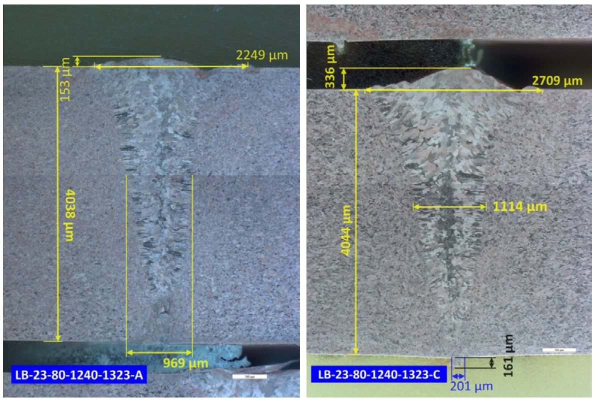

Fig. 5. Microsections of the copper butt-welds, 10 µs per shape.

An increase from 10 µs per beamshape to 200 µs per beamshape eliminates this porosity (see Fig. 6). Additional microsections show a uniform penetration depth. Microscopically, inside the weld seam there are no pores and blowholes are.

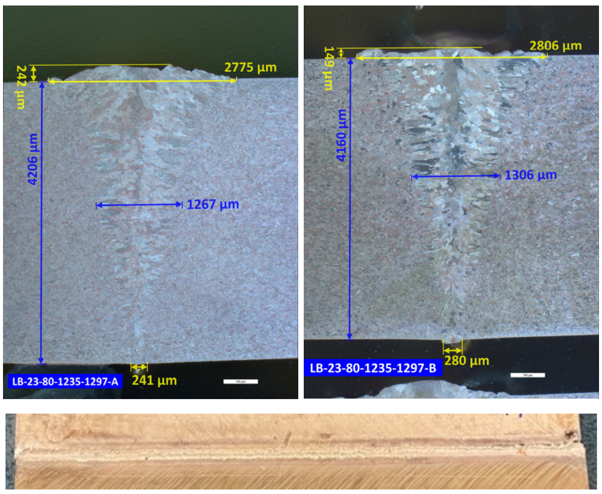

Fig. 6. Microsections of the copper butt-welds, 200 µs per shape and a macrographic of the welded specimen.

The welding results hint at positive influences of beamshape sequences when welding Al 5754 specimens.
In comparison, welds that use a tailored beamshape sequence (Fig. 7b) in contrast to a static dot beamshape (see Fig. 7a) achieve significantly increased interface widths. During the experiments an increase from an interface width below 900 µm to over 1100 µm can be observed while maintaining crack-free and pressure-tight weld seams (see Fig. 7).

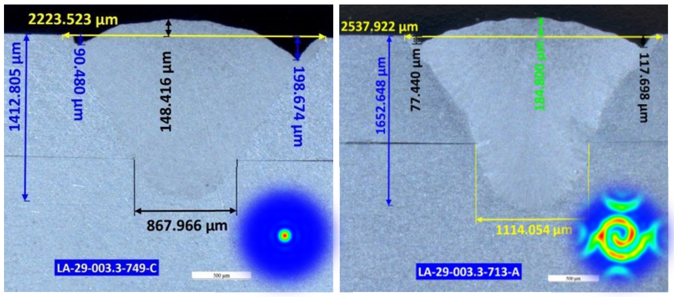

Fig. 7. Microsections of the Al5754 overlap-weld, (a) static dot beamshape, (b) spiral beamshape sequence with increased interface width.

4. Conclusion

The high quality and productivity requirements placed by the industry can be faced by using Dynamic Beam Lasers. Tailored beamshape sequences and control of the time per shape show a positive influence on the resulting welds. The investigations show that the use of a DBL to generate beamshapes and sequences allows to control the weld geometry. Furthermore, adjusting mechanical properties, surface roughness and metal structure will be evaluated in further research. Especially in the field of ever-increasing diversity of asymmetrical parts, thick or coated workpieces, different materials or alloys that need to be permanently joined the Dynamic Beam Laser starts where the possibilities of conventional technologies end.

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