Lasers in Manufacturing Conference 2021

Fully reflective annular laser beam shaping for laser beam welding at 16kW

Matthieu Meunier[a], Romain Cornee[b], Aymeric Lucas[a], David Lemaitre[b], Pierre Vernaz-Gris[a], Gwenn Pallier[a,*], Eric Laurensot[b], Olivier Pinel[a]

[a]*Cailabs, 38 Boulevard Albert 1er, 35200 Rennes, France*
[b]*Institut Maupertuis, Campus de Ker Lann, 4 Contour Antoine de St Exupery, 35170 Bruz, France*

Abstract

Laser Beam Welding (LBW) is commonly used in many fields of the industry, ranging from automotive and naval to aerospace. In order to improve LBW performance (process speed and quality as well as thickness of the parts to be weld) handling higher power, shaping the laser beam and reducing the focus shift are key.
We describe here a beam shaper compatible with industry standard equipment. The fully reflective design ease the heat evacuation leading to a reduced focus shift thanks to the absence of thermal gradient inside the optics, leading to better beam stability and process.
We demonstrate here the system capability to shape the input beam into an annular shape of high quality. The process tests are performed at multi-kW level up to 16kW with a high stability over the whole process. The process test results and the weld quality improvements are described for different materials.

Keywords: Multi-Plane Light Conversion ; Beam Shaping ; Laser Beam Welding ; multi-kW ; Focus shift

1. Introduction

Laser Beam Welding (LBW) is used for decades for industrial applications from the automotive to the naval industry. The very high level of energy applied on the surface to be welded provides important advantages compared to other welding solutions: the process is automated and therefore very repeatable, its speed is increased, and the weld quality is better with a higher depth of penetration. Indeed, Laser Beam Welding

* Corresponding author.
E-mail address: gwenn@cailabs.com .

enables deep penetration welding (keyhole welding), a welding regime in which the metal is vaporized creating a hole, called “keyhole”, leading to improved depth of penetration.
LBW still has challenges to take up:

- Improvement of the process robustness: Focus shift, or thermal lensing, is limiting the process robustness. The lenses of most laser heads will absorb some power during the multi-kW processes, which leads to a change of the distance between the last lens and the waist of the laser. The focus shift reaches more than 10cm for many standard laser heads at a typical power of 7kW, limiting the process robustness.
- Welding of thicker parts: Increasing the power on the material has led to the improvement of the depth of penetration and therefore the thickness of the welded parts. Still there are limitations to a simple increase of laser power, as the energy on the material must be applied in an optimized way.
- Complex metal welding: Laser Beam Welding of some materials is challenging such as dissimilar alloys: Al-Mg, Mg-Ti or Al-Li alloys, used in aerospace industry Baqer et al, 2018, Xiao et al, 2014. Indeed, the generation of brittle when welding those allows is complex to handle.
- Quality improvement: Most Laser Beam Welding processes will present cracks, inclusions, or spatters. Limiting those defects is a challenge to be addressed, and an optimal thermal profile ween by the material will do so. This is made possible by applying a tailored shaped beam on the material.

Many of these challenges can be addressed using beam shaping. In this article we demonstrate the capability of a laser head delivering a ring shape based on Multi-Plane Light Conversion (MPLC) technology to improve the quality of the welds, handle high power up to 16kW, and remove the focus shift.

2. A tailored laser head based on MPLC technology

2.1. Multi-Plane Light Conversion technology

There are different technologies to shape laser beams based on ray tracing, diffraction, or mode handling. MPLC is a unique way to propagate beams based on the propagation of each single mode, Labroille et al, 2014. The light will go through different phase plates with propagation in between the plates. MPLC is implemented in a reflective way to have a more robust system, easier to align, and handling higher energy and power.

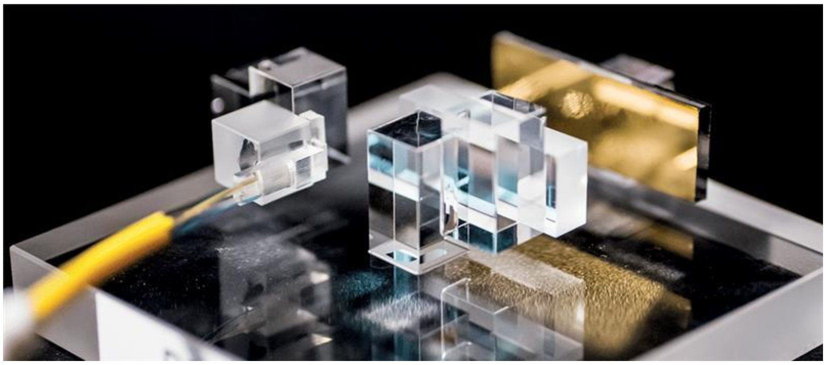

Fig. 1. A MPLC for telecommunication applications

In this article the MPLC technology is implemented within a laser head for the first time, each phase plates being one individual mirror. The head additionally includes one collimation mirror in front of the fiber LLKD connector and on focusing mirror. The laser head is designed to be compatible with a TruDisk 16002 laser

(0.1 Numerical Aperture and 200µm fiber core diameter).

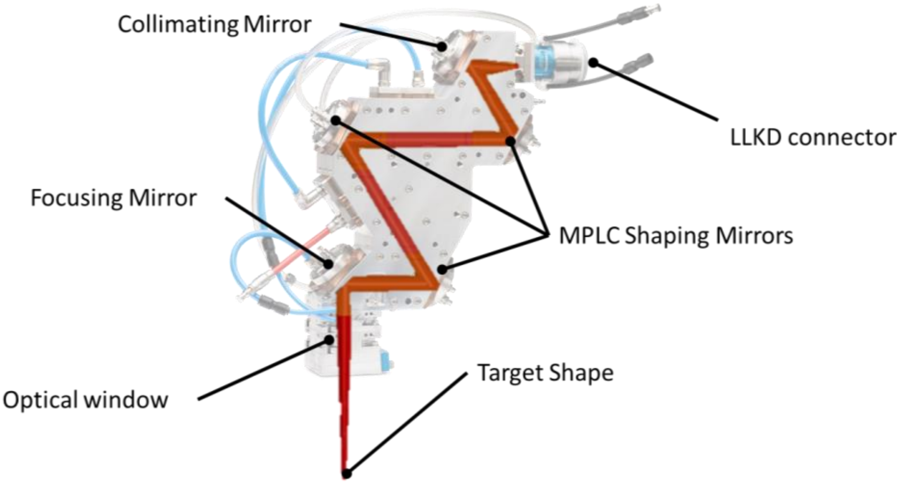

Fig. 2. Optical path through the MPLC-based laser head

2.2. Optical performance of the laser head

2.2.1. An annular beam shaping

The shape in the processing plane is annular with a 600µm inner diameter and a 1mm outer diameter. The homogeneity along the ring is 10% RMS.

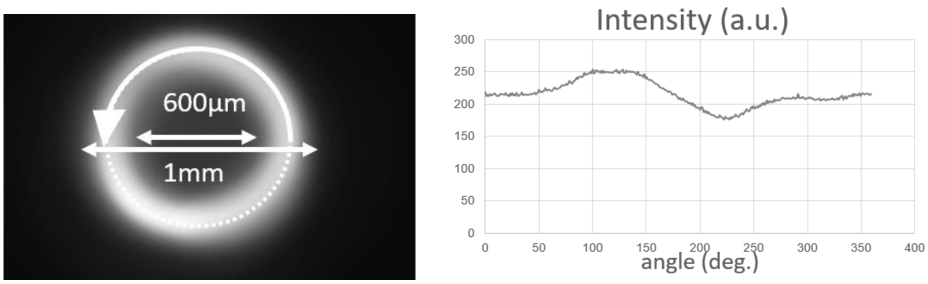

Fig. 3. (a) Intensity measurement of the output shape at low power; (b) intensity along the ring (a.u.)

The caustic of the beam has been measured using a PRIMES Focus Monitor FM&PM10 and no astigmatism is observed.

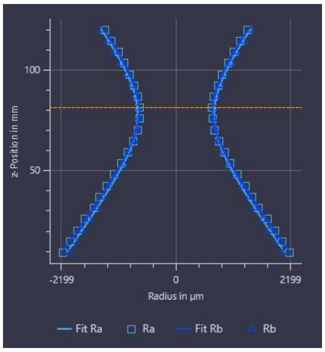

Fig. 4. Caustic measurement over 600mm

2.2.2. Depth of Field

The depth of field is of high importance for a robust process. Indeed, if the shape of the beam is not stable over a given range around the waist, the energy profile seen by the material will not be correct, limiting the thickness of the parts to be welded, and reducing the robustness of the process in case the material is not perfectly flat for example. Most of beam shaping technology don't control the phase of the beam in addition of the control of the intensity profile. MPLC enables that control, leading to a depth of field of a shaped beam comparable to the depth of field of the initial beam. In the case of this study, measurements using PRIMES Focus Monitor FM&PM10, and it has been demonstrated that the annular shape is perfectly preserved over +3mm to -3mm around the waist.

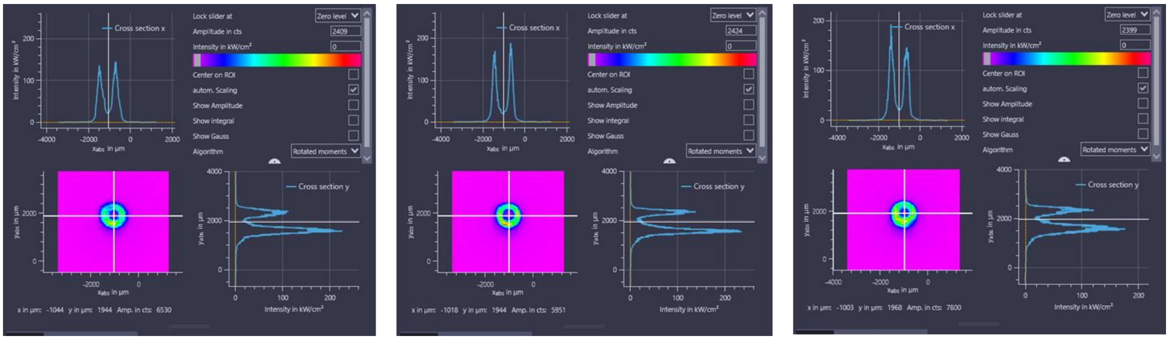

Fig. 5. PRIMES measurement of the intensity profile (a) at -3mm of the waist ; (b) at the waist ; (c) at +3mm of the waist

2.3. Thermal performance

2.3.1. Power handling

The reflective design leads to a laser head compatible with very high power. Indeed, it is possible to cool down the optics by their back, which is more efficient than a cooling by the edge as it is done on most standard laser heads with transmissive optics. In this experiment the TruDisk 16002 maximum available power was 16kW, and the laser head was compatible with such a power. The measured transmission is 99%.

2.3.2. Focus Shift removal

The focus shift at different input powers has been measured using a BeamWatch system, and a maximum focus shift of 1mm is reached without any influence of the input power.

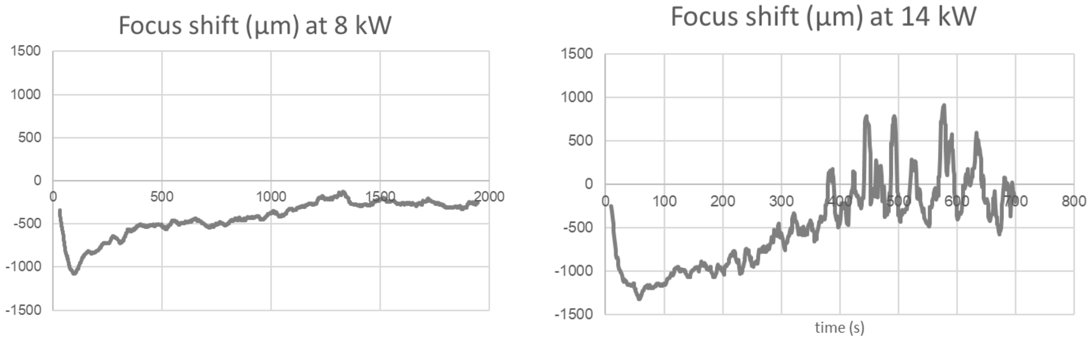

Fig. 6. Focus shift measurement (a) at 8kW ; (b) at 14kW

3. Process results

3.1. Laser Beam Welding of Stainless steel

The process parameters are the following:

- 6mm stainless steel plate
- 100mm trailing shield Argon 40L/min
- 1m/min welding speed
- Focal point 2mm inside the plate

A parametric optimization has been performed. The optimal power for this plate thickness is 7kW leading to the full penetration of the weld and a high quality of the weld with a large and smooth seam.

Fig. 7. Welding seam at 7kW

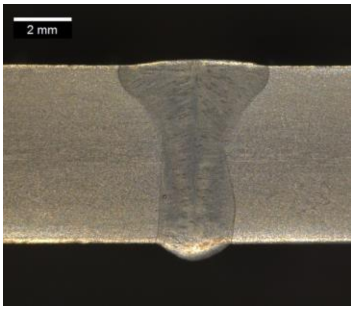

Fig. 8. Macrograph of the seam (5mm large)

3.2. Depth of Field

The welding quality is preserved when the working distance is modified confirming the extended depth of field.

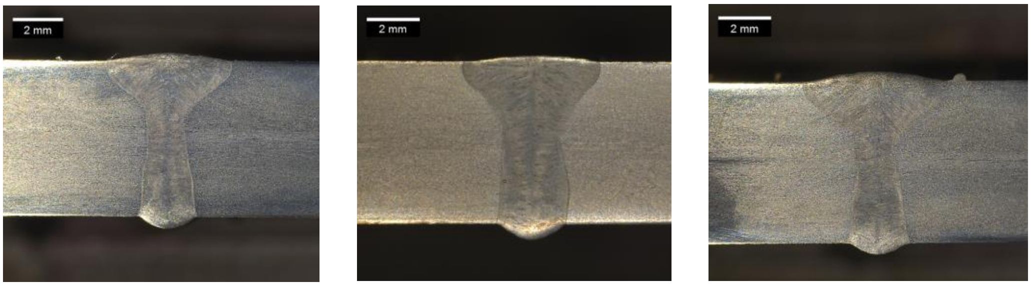

Fig. 9. Macrograph of welding (a) 1mm above the surface ; (b) 2mm below the surface ; (c) 5mm below the surface

3.3. Comparison with other technologies

A comparison has been performed with other technologies in similar conditions: with a standard output (top-hat) and with a double core fiber laser. The spot in the standard configuration is 600µm diameter The double core fiber was tested in two conditions: energy in both cores delivering a spot with higher intensity central spot and a lower intensity ring ; and energy in the outer core only. The ring generated by the double core fiber laser is 300µm inner diameter and 1.05 outer diameter.

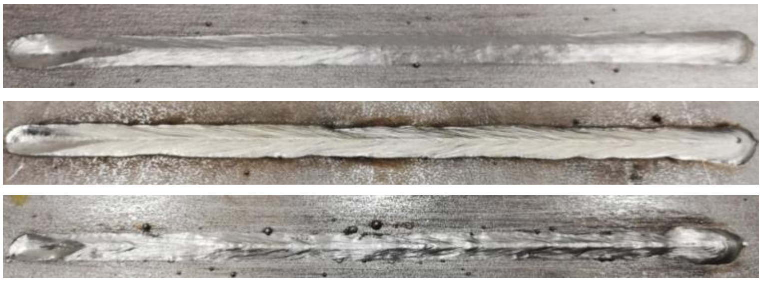

Fig. 10. Weld joints of LBW (a) with a standard output ; (b) with a double-core fiber laser, energy in both cores ; (c) with a double-core fiber laser, energy in the second core only

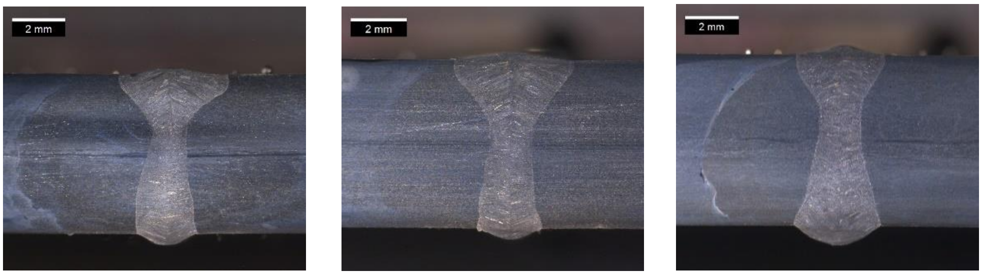

Fig. 11. Macrographs of LBW (a) with a standard output (4mm large) ; (b) with a double-core fiber laser, energy in both cores (4.3mm large) ; (c) with a double-core fiber laser, energy in the second core only (3.3mm large)

As a conclusion, the weld quality with the MPLC-based laser head is better: the weld joint is thicker, smoother, more symmetric, and less spatters are seen.

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