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Enhancing Laser Welding Performance of 6082 Aluminum Alloys with BrightLine Technology and Rotating Bifocal Optics

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Abstract

The increasing demand for lightweight, high-strength materials has led to the widespread use of aluminum alloys, in various industries. However, welding these alloys, particularly 6082, presents challenges due to their composition, which includes magnesium and silicon. The differing melting points of these elements cause inconsistent melting and solidification, leading to issues such as porosity, cracking, and reduced strength in the heat-affected zone. This study focuses on optimizing BrightLine and Rotating Bifocal Optics techniques to improve weldability and reduce defects like cracks and porosity in 6082 aluminum alloys. Both methods were successfully optimized, achieving the desired welding results.

Keywords: Rotating Bifocal Optics, BrightLine, Laser Welding, 6082 Aluminium Alloys, Disk Laser, Solid State Laser

1. Introduction

Laser welding technology provides significant advantages over traditional methods, including high precision, minimal thermal distortion. However, there are still problems, especially with newly produced materials. To overcome typical welding defects, various techniques such as BrightLine, multi-beam laser, and wobble welding are used. In this research, Rotating Bifocal Optics (RBO) and BrightLine technology were further developed to overcome this common challenge. Regarding 6082 aluminum alloy, controlling heat input, heat-affected zone stability, and beam distribution is critical due to the alloy's magnesium and silicon content, which increase hot cracking risks (Verma et al., 2023; Ostermann, 2015). Silicon, with its higher melting point (1414°C) compared to aluminum (660°C) and magnesium (650°C), plays a significant role by causing differential solidification, which can lead to microstructural defects that compromise the mechanical properties of the welded joints (Ion, 2005). Advanced laser welding techniques such as BrightLine, introduced by Trumpf in 2018, use a patented 2-in-1 optical cable with a wedge beam switch to optimize power distribution between core and ring, improving weld quality and reducing defects like porosity (TRUMPF, 2024; Feuchtenbeiner et al., 2019). BrightLine offers remarkable flexibility by allowing laser power to be directed entirely to the core fiber, the ring fiber, or distributed between both. This study also explores RBO, where the beam divides in two beams with equal laser power and rotating around a specific radius with the same values. The primary aim of this research is to minimize pore and crack formation in welded 6082 aluminum alloy by applying both BrightLine and RBO techniques and determining their optimal welding parameters, so that the welded zones remain free of defects.

2. Experimental Setup

The BrightLine weld technology, as illustrated in Figure 1, operates by distributing laser power between the central core and the surrounding inner cladding of a double clad fiber. The laser power can be directed entirely at the core fiber, the ring fiber, or split between both, significantly increasing flexibility for different material types and thicknesses (Haug et al., 2019). Figure 1 right shown the RBO, which was developed by the LMB Company (Lasermaterialbearbeitungs GmbH, Iserlohn, Germany). Here a wedge splits the laser beam into two beams with equal laser power. The rotating of the wedge with a servo motor rotates both beams around a certain radius with the same values, allowing better temperature control of the welded part.

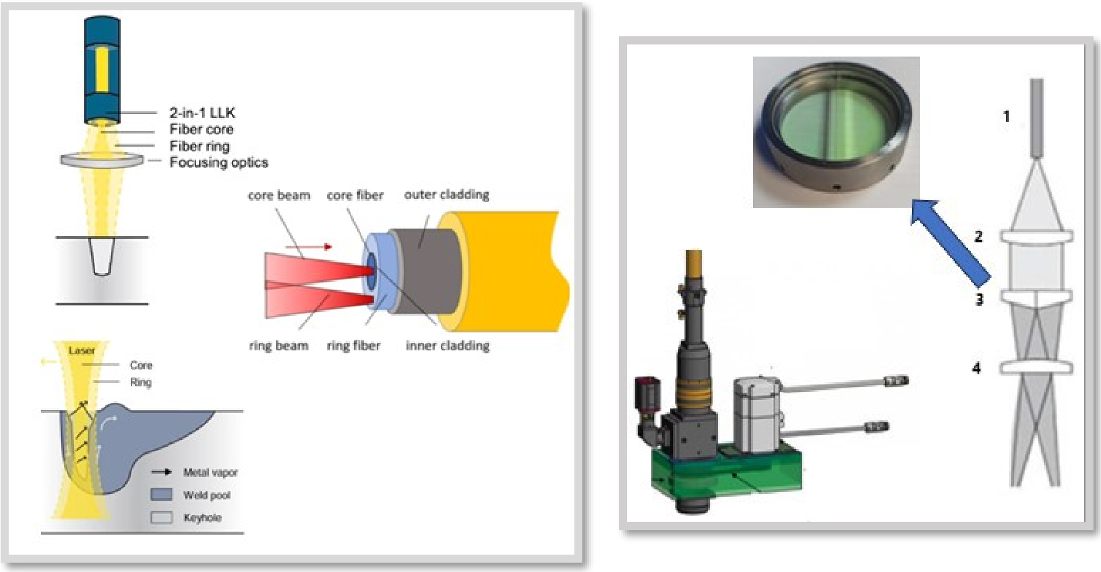


Figure 1: Bright-Line fiber (left) and RBO (right):
(1. Laser light cable, 2. Collimator, 3. Wedge, 4. Lens) (TRUMPF, 2024; LMB 2024)

In this study, for the BrightLine technic was applied using a TruFiber 6000S fiber laser with a total output power of 6 kW, specifically designed for high-performance industrial applications. For the RBO a TRUMPF TruDisk-4001 laser was used for welding aluminum 6082 alloys which provides a more focused and uniform energy distribution during the welding process. All experiments were conducted on specimens made of 6082 aluminum alloy, with dimensions of 100 mm × 200 mm × 10 mm. During the BrightLine welding experiments, the maximum laser power was set to 6 kW. Inner core power varied between 1 kW and 4.5 kW, while outer ring power ranged from 1 kW to 5 kW. Welding speeds of 30 mm/s and 100 mm/s were tested. Meanwhile, the RBO experiments were conducted with welding speeds of 2000 mm/min, 4000 mm/min, and 6000 mm/min, laser power of 2 kW, 4 kW, and 6 kW, and rotation speeds between 2500 rpm and 5000 rpm. Shielding gas was argon. Additionally, bifocal distances were tested at 0.4 mm, 0.6 mm, 0.8 mm, and 1.2 mm, and the weld position was varied between 0 (focus plane) and -4 mm (focus plane in material).

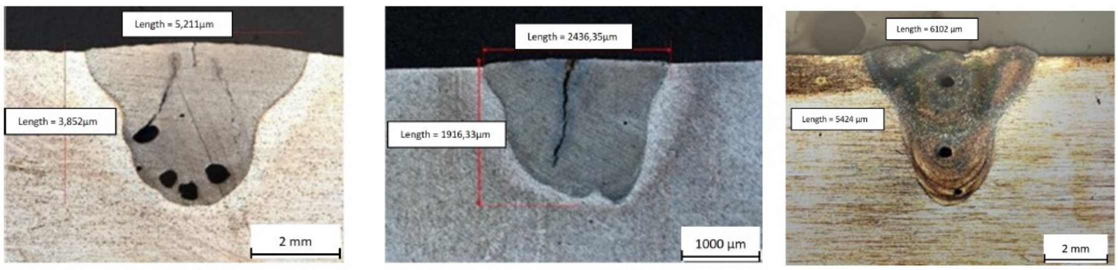
3. Results and Discussion

3.1. BrightLine Experimental Results

The aim of this study was to find the optimum welding parameters for 6082 aluminum alloys to obtain the best results by varying parameters with two different welding technics. In the experiments conducted using the BrightLine process, it was found that the outer ring power has a stronger influence on weld width than the core power. For example, at a welding speed of 100 mm/s and a total power of 5 kW, Sample 4 (Fig 2 above, left) had an inner core power of 1 kW and an outer ring power of 4 kW, resulting in a weld seams width of 2794.75 µm and a depth of 2894.63 µm. In contrast, Sample 13 (Fig.2, above right), with an inner core power of 4 kW and an outer ring power of 1 kW, showed a narrower width of 2622.55 µm but a much greater welding depth of 5414.81 µm. When the welding speed was reduced to 30 mm/s with the same total power of 5 kW, Sample 39 (Fig. 2, below, left, 1 kW core, 4 kW ring) had a weld seam width of 4482.85 µm and a welding depth of 4639.66 µm, whereas Sample 48 ((Fig. 2, below, right, 4 kW core, 1 kW ring) produced a larger weld seam width of 5823.22 µm and a deeper penetration of 5304.41 µm. These results indicate that higher outer ring power generally increases weld seams width, while higher core power results in deeper penetration. 4 kW core, 1 kW ring) produced a larger weld seam width of 5823.22 µm and a deeper penetration of 5304.41 µm. These results indicate that higher outer ring power generally increases weld seams width, while higher core power results in deeper penetration.

Figure 2: Samples are shown in order as follows: S4 (above left core: 1 kW, ring: 4 kW), S13 (above right, core: 4 kW, ring: 1 kW), S39 (below left core: 1 kW, ring: 4 kW), and S48 (below right, core: 4 kW, ring: 1 kW). Velocity: 100 mm/s (S4 & S13) and 30 mm/s (S39 & S48)

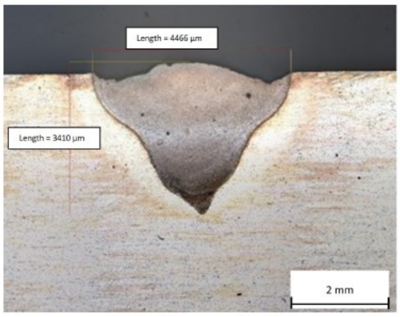
3.1. Rotating Bifocal Optics Experimental Results



Sample C5 **Sample F7** **Sample H1**

Figure 3: Cross-section of Samples C5, F7 and H1

In the laser welding experiments conducted on 6082 aluminum alloy using the RBO, several parameters such as laser power, rotation speed, welding speed, and focal distance were varied to optimize weld quality and solidification cracks and porosity. Weld experiments with argon and a bifocal distance of 0.8 mm (sample C5 (Fig 3, left, 4 kW, 3000 rpm, 2000 mm/min) showed surface solidification cracks extending deep, with many pores. Sample F7 (Fig. 3, middle, 2 kW, 4000 rpm, 4000 mm/min) had the least pores but still had cracks from surface to depth. Higher rotation and welding speeds reduced porosity but didn't eliminate cracking. Varying the focal distance and surface depth to defocus the laser spot and reduce bifocal distance helped reduce hot cracks and decrease pore formation. For Sample H1 (Fig. 3, right, 2 kW, 4000 rpm, 4000 mm/min), with the focal point set to –4 mm below the surface and a bifocal distance of 0.6 mm, pore formation was significantly reduced but not completely eliminated



Sample E4

Figure 4: Cross-section of Sample E4

In further experiments the effect of argon shielding gas was investigated using samples welded with 4 kW laser power, 4000 rpm rotation speed, 0.6 mm focal distance, and -4 mm surface depth. It was found that welding without argon significantly reduced pore formation and improved weld quality by preventing gas entrapment in the weld pool (Sample E4, Fig. 4). With optimized parameters aimed at deeper focal points, adjusted rotation speeds, and removal of shielding gas to minimize weld defects.

4. Results and Discussion

This study investigates the weldability of 6082 aluminum alloy using two new laser welding techniques: BrightLine and RBO. The main goal was to minimize hot cracking and porosity, common challenges due to the alloy's high thermal conductivity and complex composition. For the BrightLine technique, the optimal parameters were identified as 4 kW laser power in the core, 1 kW in the ring and a welding speed of 30 mm/s, which helped reduce hot cracking and porosity by allowing more uniform heat input and promoting a homogeneous microstructure. This slower welding speed ensured sufficient heat exposure, improving weld quality and overcoming challenges.

Although argon shielding gas prevents oxidation, it can cause gas entrapment and increase porosity, reducing weld quality. Therefore, weld experiments were performed without argon. Using optimized parameters (4 kW laser power, 4000 rpm rotation speed, 0.6 mm focal distance, -4 mm focal depth, and 4000 mm/min welding speed), welding without argon resulted in crack-free welds with significantly reduced porosity.

The successful application of the BrightLine technique and RBO demonstrated their effectiveness in overcoming weldability challenges of 6082 aluminum alloy by optimizing parameters to produce high-quality, defect-minimized welds. In conclusion, selecting the right welding parameters and carefully considering argon use are critical for achieving high-quality, crack- and pore-free welds in 6082 aluminum alloy.

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