Universal tool LASER - application examples for welding of HT fuel cells as well as heat exchangers and tank systems for H_2 processing

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The laser tool is predestined for automated manufacturing processes and has already proven its suitability in many areas. In particular, joining technologies in the field of hydrogen production, its storage and for bi-polar plates have to meet the highest requirements in terms of seam quality, reproducibility and manufacturing efficiency. By the examples

- 700 bar car H2 pressure tank with laser welded connection (welding depth 25 mm),
- Laser Remote Welding of HT Fuel Cell Stacks
- Laser-welded aluminum tube-ground heat exchanger for gas liquefaction

the article presents the possibilities of modern laser beam welding technologies. Furthermore, it gives an outlook on future challenges, especially with regard to the requirements of welding bi-polar plates for upcoming applications in the field of mobility..

KEYWORDS: Laser remote welding, fuel cell, heat exchanger, multi pass welding

1. Introduction

In many industrial applications, Laser beam welding has established itself as a joining technology. By the development and availability of new laser beam sources with brilliant beam quality and adapted optical systems, laser remote welding in particular is moving into the focus of applications. The article shows possible applications for laser beam welding with a view to bipolar plates (BIP) as well as systems for hydrogen generation and storage.

2. Laser remote welding - a high speed and flexible process

2.1. Laser remote welding – principle

In laser remote welding or scanner welding, the beam is guided by angle changes of movable mirrors.. A processing field is created in which highly dynamic and precise welding can be performed. The field size depends on the working distance and deflection angle. The processing speed and size of the focus diameter on the workpiece depends on the imaging properties of the optics, beam angle of impact, laser beam quality and material. By moving an additional lens system or by changing the divergence of the unfocussed laser beam, the focal point can also be shifted extremely dynamically in the Z-direction in order to completely machine three-dimensional components without moving the processing head or the component (Figure 1).

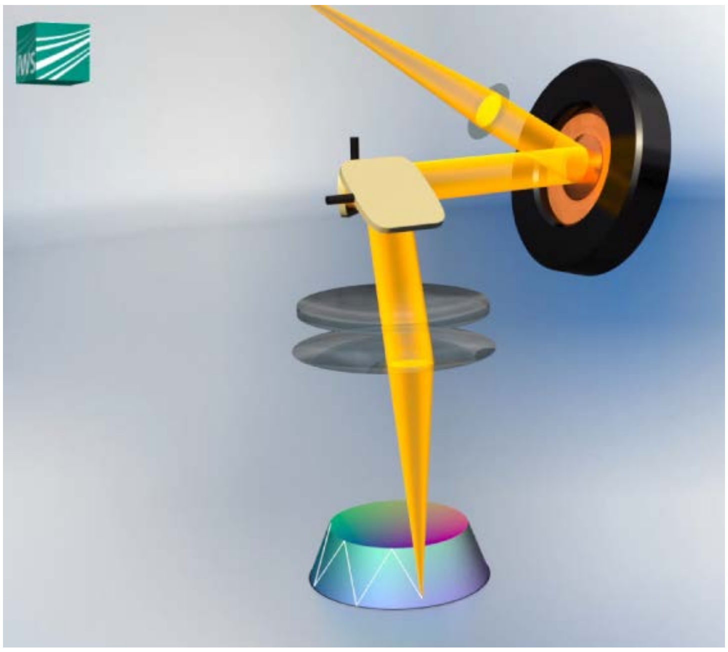

Figure 1: schematic drawing for 3D-remote laser system with 2 galvo-drive mirrows for in x-y-plane beam movement and piezo-driven mirrow for focal position

Due to the very fast offset movements, non-productive times are almost completely eliminated and the laser device can produce effectively in almost 100 percent of the available production time. During the welding process, the remote welding optics can also be guided over a workpiece in conjunction with a robot or other handling system with large working area. This "flying" movement created the term "welding on the fly": second system and scanner optics synchronize their movements with each other in real time. The use of a second handling system significantly increases the working area and enables real three-dimensional component machining.

2.2. Examples - Laser welding of HT fuel cell and heat exchangers

Laser remote welding of HT fuel cells

For high-temperature fuel cell, gas proof overlap welds are absolutely necessary . With respect to stack assembly the distortion of each component must be minimized during the whole process chain, especially at the welding process. That’s why laser remote welding using multi kilowatt fiber laser with a brilliant beam quality in conjunction with optimized clamping technology was chosen. As a result, a drastic reduction in distortion was achieved.. The welding speed could be increased by a factor of 3 compared to conventional laser beam sources (Figure 2).

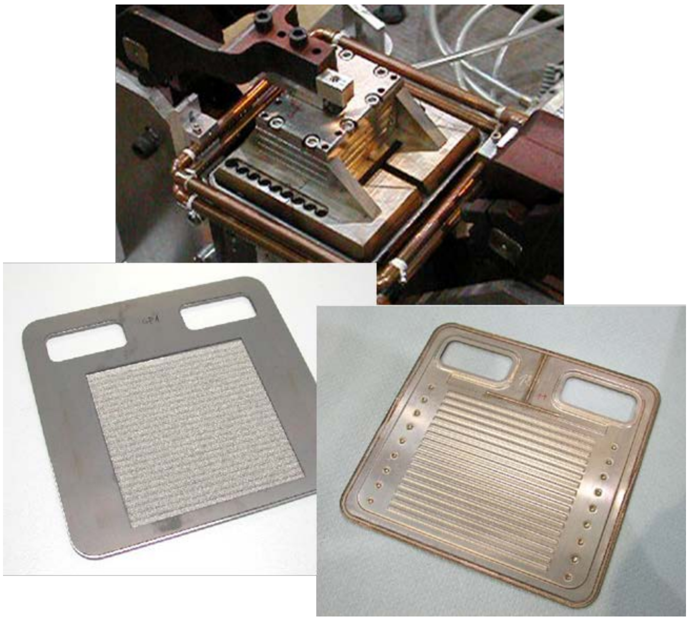

Figure 2: Laser remote welding of HT fuel cells – optimized clamping device with cooling and single parts

Laser-welded aluminum tube-ground heat exchanger for gas liquefaction

Aluminum is the preferred material for applications at low temperatures, such as those encountered in liquid gas production. The processing of aluminum by welding represents a great challenge for process technology. Laser beam welding is a highly productive joining process with regard to distortion due to its excellent thermal conductivity. However, the viscosity of the melt and easily evaporating alloying elements such as magnesium are special challenges. Besides, process instabilities with pores and melt ejections often occur. By superimposing a high-frequency beam oscillation, the stability of the welding process can be significantly improved in laser-remote welding. In this way, gas-tight welds can be manufactured on components such as heat exchangers with up to several hundred welding positions (Figure 3).

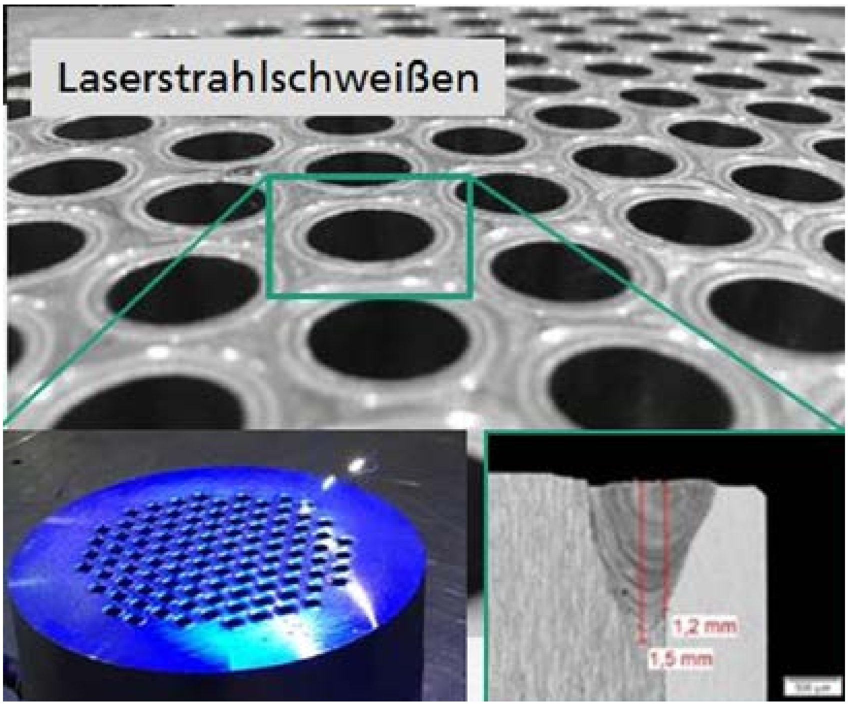

Figure 3: Laser-welded aluminum tube-ground heat exchanger for gas liquefaction

3. Welding of thick sheet aluminum components for hydrogen and liquefied gas applications

3.1. State of the art and problem

The use of aluminum is increasingly disproportionate in many areas of technology (see e.g. [H10, O98]). Despite its very good castability and extrudability into a large number of user-specific profiles and semi-finished products that can be designed to withstand high loads, the number of applications that have to be joined by welding is increasing as well. As a lightweight construction material with the best price/performance ratio, good corrosion resistance to oxidizing media and very good possibilities for final shaping, aluminum plays a key role in sustainable, resource-efficient and at the same time economical lightweight constructions. In addition to its good thermal conductivity, aluminum also has an excellent toughness at low temperatures. This makes aluminum a predestined material for gas liquefaction as well as for the storage and transport of liquid gases such as hydrogen. Especially for aluminum liquefied gas tanks and systems for gas liquefaction, the challenge in terms of production technology is to weld thick-walled aluminum components. The welding of thick parts with conventional welding processes such as MIG is usually carried out by defined weld seam preparations such as V, X or Y versions. As a rule, the required seam angles are between 40° and 60°, so that the volume has to be filled layer by layer and next to each other with a large quantity of welding/filler? wire (Figure 1).

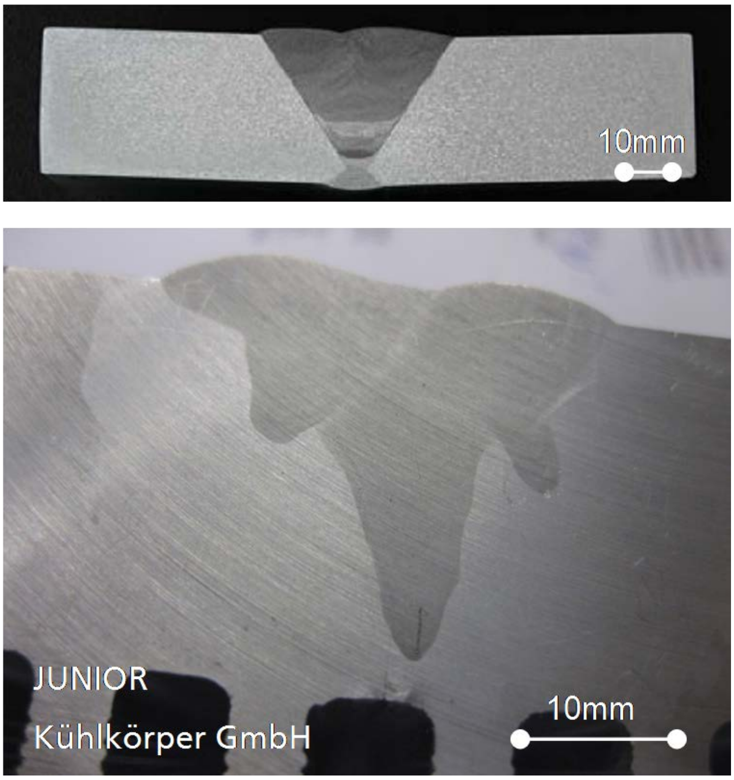

Figure 4: examples of conventional welded parts of hick sheet aluminum

3.2. Laser Multi-pass narrow gap welding - a solution approach

A solution of the mentioned problems can be the MPNG-LBW process with moderate laser power of approximately 5 kW, applied on a narrow gap. This method was already successful introduced for steel applications. In a public funded project the transfer of this technology to hot-crack sensitive aluminum materials has been investigated in order to first weld sheet thicknesses larger than 30 mm, up to 50 mm by the use of brilliant laser beam sources. The excellent beam propagation allows the laser beam to enter a narrow gap without interaction or reflection with the accompanying material. Depth limitations of the narrow gap are not restricted by the laser beam geometry any more such as in the recent past by using Nd:YAG lasers. Gaps with a groove angle of much less than 5° are acceptable with the appropriate beam quality. Restrictions on sheet thickness and groove width depend on the continuous and reliable feeding of filler wire into the gap to fill up the groove. Scanning of the laser beam transverse to the weld direction was implemented to avoid any lack of fusion to the side walls. Depending on the wire feeding speed, a defined amount of filler metal will be deposited into the gap. The necessary process steps are root welding, followed by multi-layer welding until the groove is closed, see Figure 2.

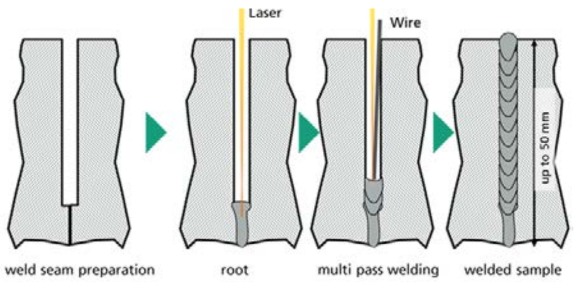

Figure 5: main process steps for the multi-pass-laser-narrow-gap-laser-beam-welding technology (MPNG-welding)

In contrast to high laser power applications in which unstable melt pools may be formed, the size of the melt pool by the new MPNG-welding process is limited. Consequently a lower defect rate in the weld seam will be expected.

3.3. Welding results and possible application

The main goal of this research work was to be able to apply the MPNG-welding technology for hot-crack sensitive aluminum alloys such as 6xxx and 5xxx on thick plates up to 50 mm. Very uniform results have been achieved with path heights at 1.5 mm to 2 mm height. In spite of the many layers it was possible to obtain a symmetrical weld seam without lack of fusion. The ratio of wire feed rate to the welding feed rate was held 1:1 at 1 m/min to 2 m/minwwleding velocity at this stage of development. The laser power had to be adapted to the spot size due to other conditions of heat conduction of the thick sheets compared to the bead on plate tests. Further investigations of welding with different beam diameters were performed. Surprisingly, the welding with a 1000 µm spot diameter and low laser power intensity of approximately 6,4E+05 W/cm² was possible and has resulted in an excellent and particularly smooth weld seam quality. Thus a wide selection of the optical configurations and laser types are potentially available and can be adapted to the specific technological needs of the application. Finally, 50 mm thick aluminum plates have been welded successfully with the MPNG-welding technology and the described edge preparation. Accordingly, the welding technology can also be transferred to thick parts. In general, even thicker parts could be welded if the filler wire can be fed continuously to the ground. The small amount of porosity shows that a high standard weld seam quality can be reached under the use of cleaned parts, the application of high quality filler wire and optimized welding parameters, see Figure 3. The component has an overall angel distortion of less than 1.4°.

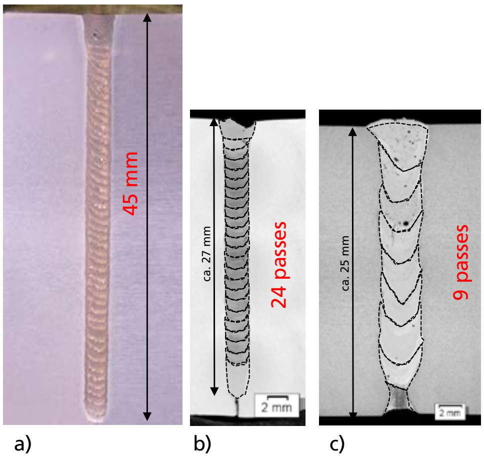

Figure 6: a) 50 mm sheet metal with 1 mm deposition rate
b, c) comparison higher layer thicknesses, left: 1 mm layer thickness, right: ca. 3 mm layer thickness

Compared to a conventional MIG-welded sample, the area of the fusion zone, which usually shows reduced mechanical properties, is extremely small at the MPNG-welding process, see Figure 4.

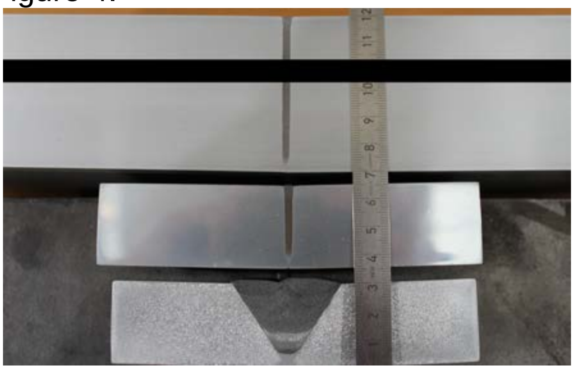

Figure 7: comparison of a conventional MIG-welded sample (bottom) to a 30 mm (middle) and 50 mm (up) MPNG-welded seam

These development results were the basis for the implementation of the technology into other applications. The flange area of a 700 bar passenger car H_2 pressure tank with a welding depth of 25 mm has successfully been welded reliably and pressure-tight (Figure 8).

Figure 8: Prototype of a 700bar car H2 pressure tank with laser welded connection (welding depth 25mm)

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