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Development of Robotized Laser Welding Applications for Joining Thin Sheets

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Abstract. Laser Welding (LW) is more often used in manufacturing due to its advantages, such as accurate control, good repeatability, less heat input, opportunities for joining of special materials, high speed, capability to join small dimension parts etc. LW is dedicated to robotized manufacturing, and the fabrication cells are using various level of flexibility, from specialized robots to very flexible setups. This paper features several LW applications using two industrially-scaled manufacturing cells at UPM Laser Centre (CLUPM) of Polytechnical University of Madrid (Universidad Politécnica de Madrid). The one dedicated to Remote Laser Welding (RLW) of thin sheets for automotive and other sectors uses a CO_2 laser of 3500 W. The second has a high flexibility, is based on a 6-axis ABB robot and a Nd:YAG laser of 3300 W, and is meant for various laser processing methods, including welding. After a short description of each cell, several LW applications experimented at CLUPM and recently implemented in industry are briefly presented: RLW of automotive coated sheets, LW of high strength automotive sheets, LW vs. laser hybrid welding (LHW) of Double Phase steel thin sheets, and LHW of thin sheets of stainless steel and carbon steel (dissimilar joints). The main technological issues overcame and the critical process parameters are pointed out. Conclusions about achievements and trends are provided.

Keywords: Robotized Welding, Flexible Cell, Laser Welding, Remote Laser Welding, Automotive, CO_2 laser, Nd:YAG laser, Hybrid Welding, Coated Steel Sheets, Dissimilar Joints

1. Introduction

Laser technologies and laser welding started a new technological age in the last decades of the 20th century, due to clear advantages for industry, namely high precision, high productivity, flexibility and the effectiveness with which these can be incorporated into automated manufacturing environments [1].

Present applications for Laser Welding (LW) include automotive, aerospace, defense, marine / ship building, medical, electronics, power generation and networks, alternative energy (fuel cells, solar power and wind turbines), nuclear, oil and gas, on- and off- highway transportation equipment, as well as home appliances. E.g., analyzing integral shell designs for aerospace structures, it results that laser beam welding could reduce manufacturing cost due to automation, less material for joining and sealing, fewer production steps, and improved corrosion behavior [1-2].

Similar and dissimilar joints of wide arrays of materials are possible to be achieved by LW, including steels, high carbon alloy steels, stainless steels, cast irons, aluminum alloys, nickel-based alloys, titanium, and plastics.

The continuous need of increasing manufacturing effectiveness determined rapid changes in terms of equipment, technologies and processes. Along the continuous technological progress, gaps are bridged every day, whilst new challenges arise. This paper addresses actual key-processes, namely remote laser welding (RLW) and laser hybrid welding (LHW), together with several correspondent applications in the field of laser welding of thin sheets of special steels, developed in Laser Center UPM.

2. Remote Laser Welding Cell

The LW process characterized by increased values of focal length (long standoff), when the laser beam is long-distance focused in the joint plane by means of two-axis mirror(s) system is usually referred as *Remote Laser Welding* (RLW).

Remote laser beam delivery, either through optical fiber or a guiding optical path, is gaining interest as an emerging technique for welding of coated steel sheets in automotive, home appliances and other mass-production industries due to its versatility and amenability to high production throughput.

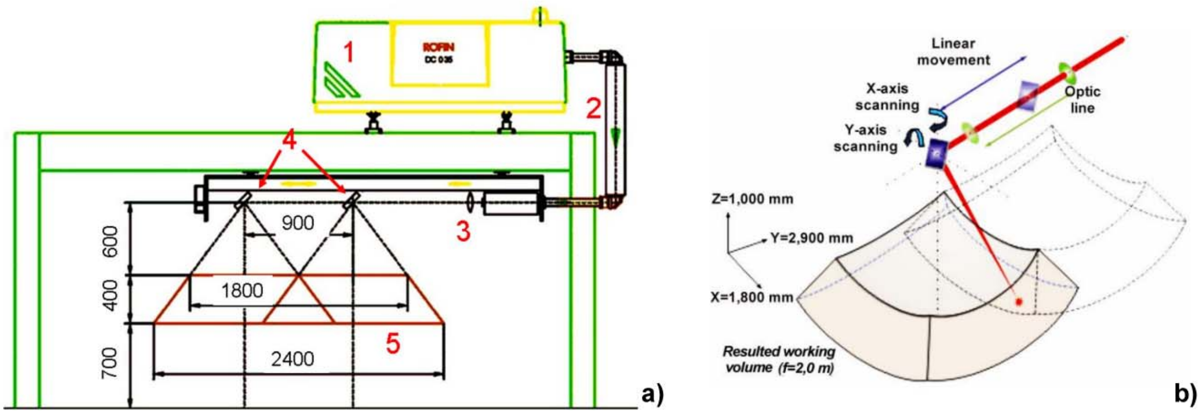

Fig. 1: Remote Laser Welding (RLW) cell at UPM Laser Centre (CLUPM): *a)* Sketch of the system: 1- laser resonator; 2- optical guidance system; 3- adjustable focalization optical system; 4- scanning mirror in extreme positions; 5- working area. *b)* Working volume of the Remote Laser Welding cell.

Typical RLW systems with long focal length (1.2-2.0 m) have the structure as described in Fig. 1a, a working volume as shown in Fig. 1b (cell at CLUPM), and are usually equipped with CO_2 lasers (about 3.5-6 kW and higher) [3]. Advantages are related to avoidance of geometrical constrains deriving from use of welding guns or torches, or bigger and much complicated devices used in case of resistance welding. Thanks to an increased positioning ability, RLW systems make feasible to reduce costs, investments and footprint at production site [3].

The long focal for scanning inside the working volume ensures a good parallelism of the beam along the material thickness. In parallel with the last developments in RLW, involving robots operating short focal length scanners, the long focal length remote lasers are still of high interest, because such systems fully function in wide-world enterprises, very well implemented in the production lines. On the other hand, replacing more resistance spot welding with laser welding is still a target for the factories using nowadays the long-focal length RLW.

The high speed and precision scanning systems may use two galvanic mirrors, or just one (Fig. 1b); in the latter case, the single mirror must provide 2-axis scanning. The RLW system at CLUPM is equipped with a CO_2 slab laser, ensuring the beam delivery through optical guide and only one galvanometric mirror that has two scanning axis and one linear movement (Fig. 1b). The laser source is Rofin Sinar DC 035 of 3.5 kW, whose beam is handled and delivered through RWS 2.2 optical system.

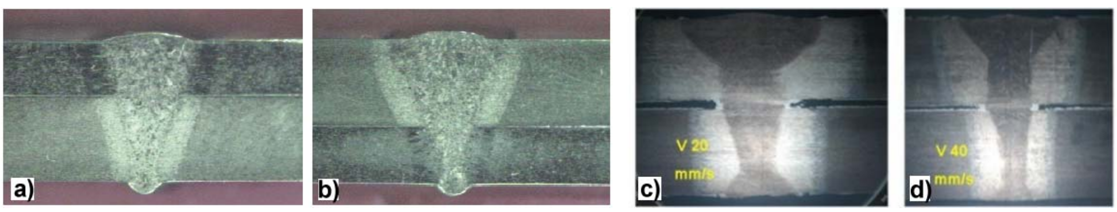

Fig. 2: RLW joints welded with 3.5 kW CO_2 laser at CLUPM: *a)* 1.6 mm ST05 Z ST05 + 2.5 mm ZStE 260 Z; *b)* 2.5 mm ZStE 260 Z + 1.6 mm ST 05 Z; *c),d)* overlap joints of 1.6 mm sheets of USIBOR 1500 coated with ALUSI; defect-free welds achieved at two welding speeds (*c)*-20 and *d)*-40 mm/s), in keyhole mode welding.

RWS 2.2 also includes the high precision scanning equipment. The whole facility is installed in a dedicated enclosure, where work pieces can be fixed with specific clamping tools, and provided with shielding gas. Monitoring and control equipment used during experiments is also situated in this enclosure. The on line monitoring of the weld pool dynamics was performed in different cases by means of a fast camera (PHOTRON Fastcam-Ultima 512), working at a capture speed of 2,000 fps.

3. Relevant Applications of Remote Laser Welding

3.1. RLW of Zn-Coated Thin Steel Sheets

A major reported problem for the achievement of high quality welds in Zn-coated steels is generated by the low vaporization temperature of this element and the related interaction of its vapor with the laser welding keyhole dynamic phenomenon [4-6].

This investigation addressed two types of galvanized automotive sheets, namely ZStE 260 Z and St 05 Z (denomination acc. DVV, equiv. SEW 093 and DIN 17 162-old, part 1, respectively). These correspond to the high-elastic limit micro-allied steel H260P (EN 10027-1) and to the non-allied forming steel DX 53 D+Z (EN 10142), respectively. In all cases, the Zn-coating nominal thickness is 10 μm [7].

Various process parameters were successively modified, to assess their influence on the weld and joint quality and to set up the weldability limits. Thus, it was possible to draw operating (feasibility) windows, allowing a quick technological assessment and design when implementing a specific RLW process.

It has been observed that a careful parameters selection is needed to obtain good quality welds, mostly due to the difficult evacuation of the *Zn* vapors (*Zn* vaporization temperature = 1,180º K), especially from the inner interface of the two galvanized plates (only no-gap overlap joints were targeted, [7]).

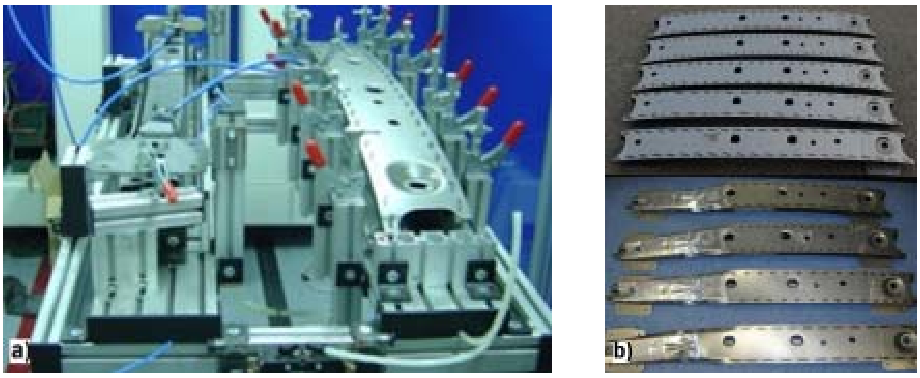

Fig. 3: Tests at CLUPM: a) experimental setup for testing RLW technologies for joining Ford Focus parts. b) Various shape stitch joints - before and after shock testing

Weld seams of 20 mm length over different combinations of thickness either of one or of both steels have been performed (Fig. 2a,b), and the corresponding results analyzed for different combinations of the processing parameters. *He* and *Ar* have been used and compared as shielding gases, and the effect of O_2 as potential inhibitor of the *Zn* vapors elimination was also tested.

Remote welding of Zn-coated steels under optically guided slab CO_2 laser beam has been shown to be feasible for typical car body construction materials and joints up to 5 mm total thickness. This method is used in the practice of the automotive plants to weld up to four overlapped thin Zn-coated plates and replaces more and more the classical resistance spot welding. The high speed (about 60 stitches of 5 mm length in 1 min, Fig. 3), accurate positioning and easy access to any point inside the working volume makes RLW a serious industrial option for mass production.

3.2. RLW of Al-coated thin steel sheets

RLW process is highly feasible for other special steels used in automotive and other industries, such as double-phase high strength steel (DP, DX, DOCOL etc.) sheets. An example of RLW joint of high strength steel Aluminum-coated sheets (USIBOR coated with ALUSI: 91% Al + 9% Si), is presented in Fig. 2c,d.

In this case, the issue is created by the numerous types of aluminum inter-metallic compounds which may appear in the weld, decreasing its strength. The main advantages of USIBOR are the very high strength (R_m = 1,500 MPa) obtained after hot stamping, as well as the high formability due to the same process. The

ALUSI coating is compatible with the hot stamping process and assures a very good corrosion protection. The welding process must damage as less as possible the aluminum protection.

There are also several concerns related to overlap and patch welding, such as the negative influence of the coating on the weldability, or the measures necessary to keep the mechanical (static and dynamic) properties obtained after thermal treatment. USIBOR may be welded coated or uncoated, but it is complicate and costly to achieve the coating after welding. On the other hand, welding may be achieved before hardening by hot plastic deformation, or after. In the latter case, the welding thermal cycle must not damage the mechanical properties of the treated USIBOR.

4. Laser Welding Using 6-Axis ABB Robot

4.1. Robotized Nd:YAG Laser Welding of Thin Sheets

In case of the flexible cell at CLUPM, the laser beam is transported by optical fiber from the Nd:YAG laser equipment of 3300 W maximum power to the ABB 6-axis robot, equipped with a welding head corresponding to the chosen technique. Fig. 4a,b shows the robot operating a laser head with a focal distance of 250 mm assuring a minimum spot diameter of 0.5 mm.

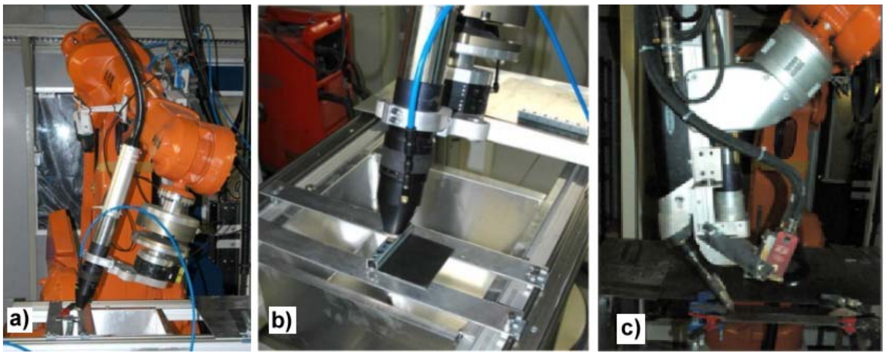

Fig. 4: ABB robot operating at CLUPM a Nd:YAG laser beam head for: *a),b)* Laser Welding; *c)* Laser Hybrid Welding; *b)* details in case of laser spot welding of aluminum automotive parts.

If appropriate devices are used, thin sheets starting from 0.35 mm can be successfully welded. Good welds were obtained for shape-memory alloys NiTi sheets of 0.5 mm [8], and also when welding stainless steel thin plates, for both butt and overlap joints.

Usually, LW is not using filler material. Fig. 5a shows welded joints of galvanized DP 1000 steel without filler material – the basic LW. If using Laser Hybrid Welding (LHW), filler material is used together with the Gas Metal Arc Welding (GMAW) process; in this latter case, the cross-section appearance of the bead is as a superposition of the appearance of the two separate processes (Fig. 5b), namely LW and GMAW.

4.2. Laser Hybrid Welding of Thin Sheets Dissimilar Joints

Important development of Laser Hybrid Welding (LHW) was noticed in the last decade in industrial applications in shipbuilding, automotive, aircraft and other industries [9]. This generic name and concept is widely understood as combination of two classic processes: GMA Welding and Laser Welding (LW), respectively. Fig. 4c presents the robot operating a complex Laser Hybrid Welding head.

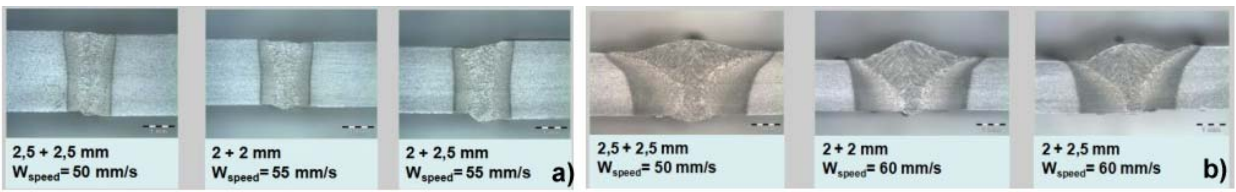

Fig. 5: LW joints of DP 1000 steel sheets at CLUPM: a) without filler material, using LW in keyhole mode; b) LHW joints of DP 1000 steel sheets with filler material using GMAW + LW in keyhole mode.

The advantages of arc welding are low cost energy source, gap bridgeability, constitution (microstructure) that can be influenced etc., whilst the advantages of using laser welding are the increased penetration, high welding speed, low thermal influence, high mechanical performances etc.

As a holistic approach, LHW is meant to bring mainly low heat input, low deformation, better metallurgical quality, higher welding speed, low distortion, higher bridgeability, and lower spattering.

The process allows the design of the material constitution in the weld, which is highly requested especially when welding different material, to achieve quality dissimilar joints [10]. E.g., in case of stainless steel-carbon steel dissimilar joints (Ferritic-Austenitic, also called "Black and White" joints), the main issue to overcome is the formation of deleterious constituents, that occurs if the chemical composition is not strictly controlled. This is possible by choosing the appropriate filler material and controlling the heat input in each of the two types of plates [10,11].

5. Conclusion

Time savings, the flexibility enhancement and design possibilities that RLW offers are threshold references for nowadays industrial manufacturing.

Further LHW development can address welding of dissimilar joints, allowing a good prediction and control of the heat input and apportionment in each plate. This also opens a challenging new topic in fracture mechanics and complex characterization of heterogeneous medium.

6. Acknowledgements

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