Recent achievements and trends in laser welding of thin plates

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Laser Welding (LW) is more and more chosen as manufacturing process due to its advantages, namely capability of joining small dimension parts, opportunities for joining of special materials, less Heat Affected Zone, good repeatability, high speed etc. Nowadays, LW is of particular interest in manufacturing small mechatronics parts of mechanic, electric or electronic nature. This paper underscores several achievements in three key-processes, namely classical LW, laser hybrid welding (LHW) and remote laser welding (RLW). These results were obtained at the UPM Laser Centre (CLUPM) of Polytechnical University of Madrid (Universidad Politécnica de Madrid) with a CO_2 laser of 3350 W dedicated to RLW of thin sheets for automotive and other sectors, and with a Nd:YAG laser of 3300 W, respectively. The second is operated by a 6-axis ABB robot and is meant for various laser processing methods, including welding. Several important applications experimented at CLUPM and recently implemented in industry are briefly presented: RLW of coated sheets (with Zn or Al), LW of thin sheets of stainless steel and carbon steel (dissimilar joints), LW of high strength automotive sheets, LW vs. laser hybrid welding of Double Phase steel thin sheets, LW of Shape Memory Alloys (NiTi). The way in which the team of CLUPM has addressed some knowledge gaps related to LW, LHW and RLW are underscored, together with the benefits of the new technologies for both science and industry.

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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, assuring their effective implementation into automated manufacturing environments, as discussed by Engler (2006).

Present applications for Laser Welding (LW) include sectors such as automotive, aerospace, defense, marine and ship building, medical, electronics, power generation and networks, chemical industry, 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 consumed for joining and sealing, fewer production steps, and improved corrosion behavior, as presented by Southwell et al. (2006).

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

The continuous need of increasing manufacturing effectiveness has determined rapid changes in terms of equipment, technologies and processes. E.g., remote laser welding (RLW) is replacing more and more the resistance spot welding in automotive and home appliances manufacturing.

Beside the classical LW, this paper addresses actual key-processes, namely 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 UPM Laser Centre (CLUPM).

2. Remote laser welding

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 the welding of coated steel sheets in the automotive, home appliances and other mass-production industries in view of its versatility and amenability to high production throughput.

Typical RLW systems with long focal length (1.2-2.0 m) have the structure as described in Fig. 1, a working volume as shown in Fig. 2 (is the case of the RLW cell at CLUPM) and are usually equipped with CO_2 lasers about 3.5-6 kW and higher (Herfurth et al., 2005).

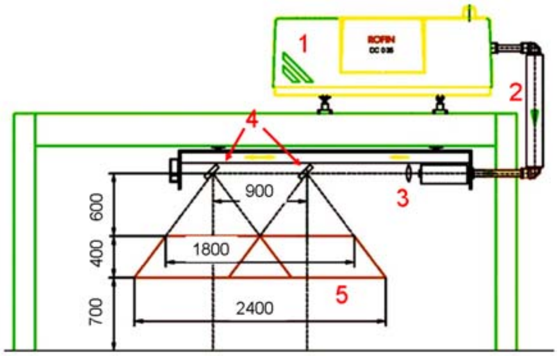

Fig. 1. Sketch of the remote laser welding (RLW) system functional at CLUPM: 1- laser resonator; 2- optical guidance system; 3- adjustable focalization optical system; 4 - scanning mirror in extreme positions; 5- working area.

Advantages are related to avoidance of geometrical constrains deriving from use of welding guns or torches. Thanks to an increased positioning ability, RLW systems make feasible to reduce variable costs, investments and footprint at production site, as discussed by Herfurth et al. (2005).

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 (Rath, 2005), the long focal length remote lasers are still of high interest, because such systems fully function in factories wide-world implemented in flexible production lines. On the other hand, replacing more resistance spot welding with laser welding is still a target for the manufacturers using nowadays the long-focal length RLW (Iordachescu, D., 2007).

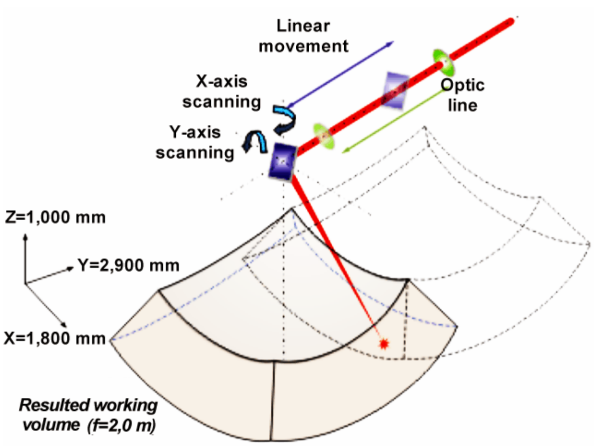

Fig. 2. Adjustable focalization optical system and working volume of the remote laser welding cell at CLUPM.

The high speed and precision scanning systems may use two galvanic mirrors, or just one; in the latter case, the single mirror must provide 2-axis scanning (Fig. 2).

This 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. 2). The laser source is Rofin Sinar DC 035 of 3.5 kW, whose beam is handled and delivered through RWS 2.2 optical system.

RWS 2.2 also includes the high precision scanning devices. The whole facility is installed in a dedicated enclosure, where work pieces can be fixed with specific clamping tools, and provided with shielding gas and other necessary devices. Monitoring and control equipment used during experiments is also situated in this enclosure.

3. Applications of remote laser welding

3.1 RLW of Zn-Coated Thin Steel Sheets

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.

A major problem jeopardizing the achievement of high quality welds of Zn-coated steel sheets is generated by the low vaporization temperature of this element and the related interaction of its vapor with the laser welding keyhole dynamic phenomenon, as often reported.

This paper first refers RLW of 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), with the chemical composition presented in Table 1. In all cases, the Zn-coating nominal thickness was of 10 μm (Ocaña, 2009).

Table 1. Chemical composition (wt‰) of the ZStE 260 Z and St 05 Z automotive sheets.

	C [‰]	Mn [‰]	Si [‰]	S [‰]	P [‰]	Al [‰]
ZStE 26 Z	2	55	84	8	70	37
St 05 Z	1	13	5	10	16	28

It has been observed that obtaining good quality welds needs a careful parameters selection, mostly due to the difficult evacuation of the *Zn* vapors (*Zn* vaporization temperature = 1,180º K) from the two galvanized plates inner interface. Avoiding the welding with “artificial” gap (a method that is meant to assure the *Zn* vapors evacuation, but is costly and time consuming), only no-gap overlap joints were achieved, as illustrated in Fig. 3.

Weld seams of 20 mm length over different combinations of thickness either of one or of both steels have been performed (Fig. 3) 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 for Zn-vapor elimination was also investigated.

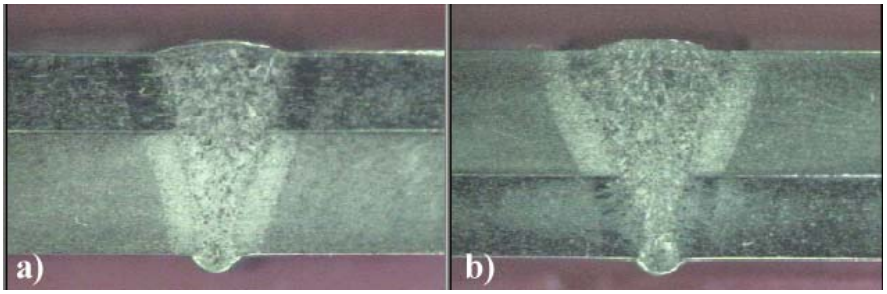

Fig. 3. RLW joints welded with 3,5 kW CO_2 laser at CLUPM: a. 1.6 mm ST05 Z ST05 + 2.5 mm ZStE 260 Z; b. 2.5 mm ZStE 260 Z + 1.6 mm ST 05 Z.

Remote welding of Zn-coated steel sheets under optically guided slab CO_2 laser beam has been shown to be feasible for typical car body construction materials and overlap 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.

3.2 RLW of aluminum-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 (DP, DX, DOCOL etc.). An example of RLW joint of high strength steel Aluminum-coated sheets (USIBOR coated with ALUSI: 91% Al + 9% Si), is presented in Fig. 4.

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.

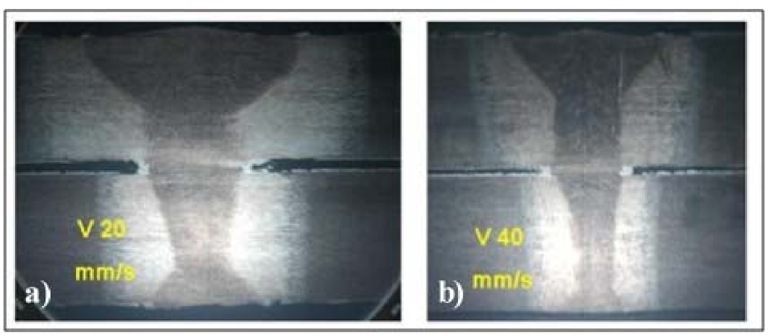

Fig. 4. RLW joints welded with CO_2 laser at CLUPM: USIBOR 1500+ALUSI, defect-free welds achieved at two welding speeds (20 and 40 mm/s), keyhole mode.

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 decrease the mechanical properties of the treated USIBOR.

The high speed (about 60 stitches of 5 mm length each in about 1 min, Fig. 5), accurate positioning and easy access to any point inside the working volume makes RLW a serious industrial option for mass production.

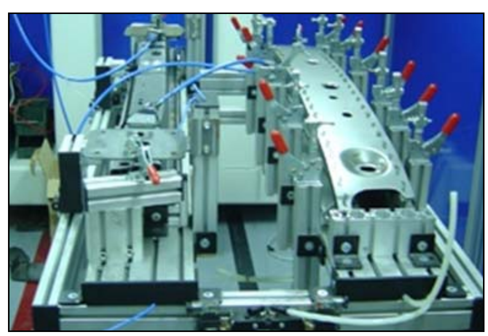

Fig. 5. Experimental setup at CLUPM for testing RLW technologies for joining a Ford Focus part.

4. Nd:YAG laser welding

4.1 Nd:YAG laser welding of thin sheets

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

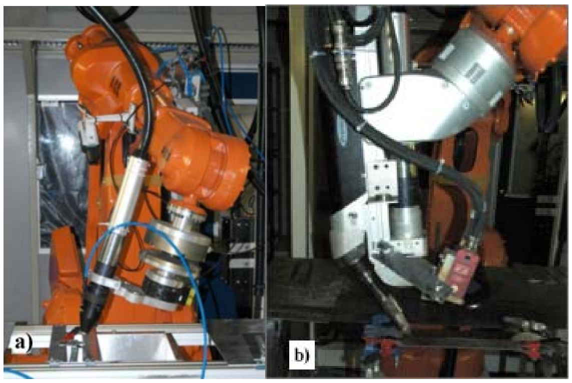

Fig. 6. ABB robot operating a Nd:YAG laser beam at CLUPM for: a. laser welding b. laser hybrid welding.

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 (Alberty et al, 2010), and also when welding stainless steel thin plates. Fig. 7*a* shows quality butt welded joints made of AISI 304 stainless steel of 0.5 mm, whilst Fig. 7*b* presents an overlap welded joint of the same plates.

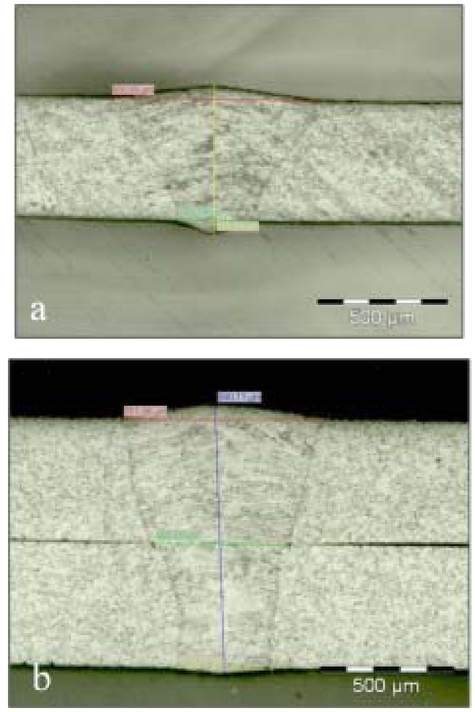

Fig. 7. LW of AISI 304 stainless steel of 0.5 mm at CLUPM: a. transition from conduction to keyhole mode welding; b. keyhole mode welding.

Fig. 7 illustrates the different techniques used for laser welding in these two cases; this makes laser welding a versatile method, allowing welding by conduction, transition (Fig 7*a*), or keyhole mode (Fig 7*b*).

Usual LW is not using filler material. Fig 8 shows welded joints of galvanized DP 1000 steel without filler material – basic LW. If using Laser Hybrid Welding, filler material is used together with the GMAW process (Fig. 9).

Fig. 8. LW joints of DP 1000 steel sheets without filler material, using LW in keyhole mode at CLUPM.

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. This generic name and concept is widely understood as combination of two classic processes: GMA Welding and Laser Welding (LW), respectively. Fig. 6*b* presents the Laser Hybrid Welding head operational at CLUPM.

Fig. 9. LHW joints of DP 1000 steel sheets with filler material using LHW in keyhole mode at CLUPM.

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 (Iordachescu, D., 2011). E.g., in case of stainless steel-carbon steel dissimilar joints (Ferritic-Austenitic, also called "Black and White"), the main issue to overcome is the formation of deleterious constitutions, 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 plate (Iordachescu, M., 2010).

5. Conclusions

Time savings, 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.

Acknowledgments

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