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ScienceDirect
Physics Procedia 12 (2011) 194–200
Physics Procedia

LiM 2011

Development of Plasma-Laser-Hybrid Welding Process

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Abstract

In order to fulfill demands for quality and efficiency in the field of welding engineering, numerous works in research on the optimization of the welding processes are in progress. [1] Aims of this research are increasing the welding speed, stabilizing the welding processes, decreasing the reject rate and reducing the pre and post welding machining. This work relates to the development of a new plasma-laser hybrid welding method in order to increase the productivity of the existing technologies of plasma arc welding and laser beam welding and to compensate their disadvantages, by using common machinery.

Keywords: hybrid; welding technology; plasma arc; laser beam.

1. Motivation

High productivity and quality issues for welding processes supported Laser Beam Welding (LBW) process to become increasingly important for joining metallic parts in recent years. The advantages of this welding process are in addition to high speed welding a small heat affected zone and low thermal distortion of the work piece. The main disadvantage of the LBW is the small gap bridging ability, which is an advantage of arc welding processes. However with Metal Arc Welding (MAW) processes, such as MSG or the TIG welding, no such high welding speeds are realizable, due to lower power densities. Plasma Arc Welding (PAW) process was created, as the enhancement of the TIG welding process, and achieves intensities close to laser beam welding process. PAW combines the advantages of LBW, like high intensity, and MAW, like gap bridging. But the main disadvantage of PAW is the process instability.

In order to compensate the respective disadvantages of different welding processes hybrid welding processes have been developed. The main feature of those processes is the combination of existing processes to unify the advantages and compensate the disadvantages.

A laser-plasma hybrid process has been developed. In this process the function of plasma arc is bridging the gap between work pieces and the function of laser beam is to create the keyhole-effect, which requires high power laser

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doi:10.1016/j.phpro.2011.03.025

(> 1 kW). [2] But the purchasing of high power laser is very costly and often can not be afforded by small and medium-sized enterprises.

This work relates to the development of a new plasma-laser hybrid welding method in order to increase the productivity of the existing methods (PAW and LBW) and to compensate their disadvantages. Some earlier works describe interactions between plasma arc and laser beam. Those interactions cause a focusing effect of plasma arc, which increases the efficiency of the welding process. The focusing effect can be observed by using low power laser (< 500 W). First experiments confirm the focusing effect and show that the penetration is deeper than that of the plasma only process.

The Plasma-Laser-Hybrid Welding Technology combines conventional plasma and laser machinery to produce a highly economic welding source. Advantages of that new process from the economic point of view are higher productivity, faster process and relatively low costs of the equipment. But also the quality of joins can be increased by this newly developed process. The arrangement of used equipment is shown in figure 1a schematically. Plasma-laser-hybrid process combines PAW process and LBW process. Each of them has numerous factors which have an influence on weld quality. By the combination of PAW and LBW new actuating variables came up, as shown in figure 1b.

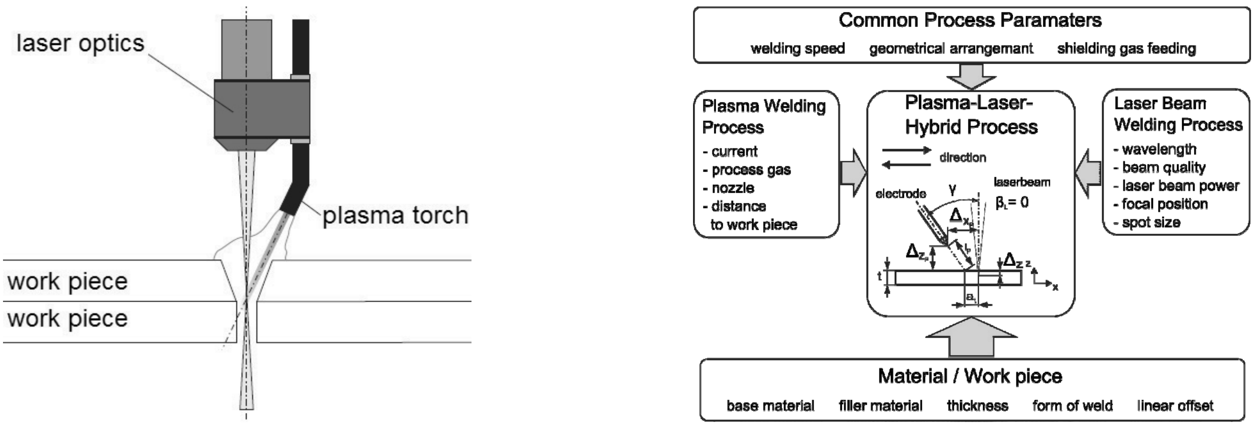


Figure 1. (a) arrangement of machinery; (b) actuating variables of plasma-laser-hybrid welding process [1]

2. Experimental

First experiments were done on a conventional PAW process in order to investigate the influence of different variables, like angle, process gas volume flow rate, arc length, welding speed etc. Those investigations have shown which factors significantly influence the welding quality and which have less influence on the joining process.

After PAW process has been stabilized and the parameters for successful welding were found, interactions between plasma arc and laser beam were investigated. Some works describe plasma arc and laser beam interactions on aluminum materials. Welding speed and joint quality could both be increased by these effects. But there are few studies on steel materials, which come to conflicting conclusions. [3] [4] Therefore the behavior of plasma arc influenced by laser beam was investigated.

The next step was to define the appropriate parameter window for the newly developed joining process. During the investigations various combinations of parameters, like angels, welding speed, laser beam power, focal position, spot size, etc. were analyzed. The arrangement of used equipment is schematically shown in figure 2. For coupling of common machinery a new developed processing head has been used (figure 3). This processing head allows the adjustment of various degrees of freedom and makes it possible to investigate the influence of different parameters

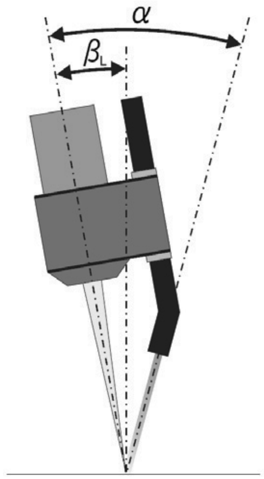


Figure 2. hybrid process

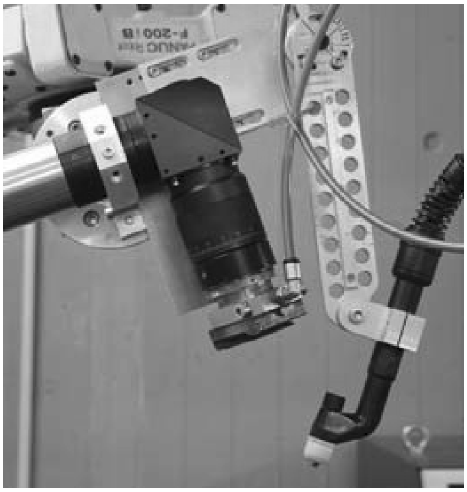


Figure 3. hybrid processing head in detail

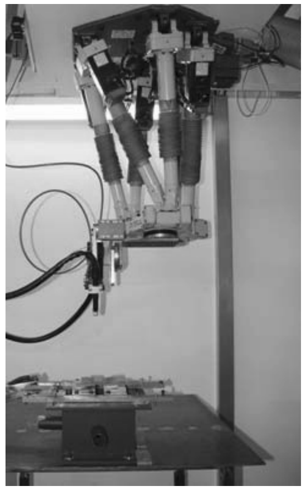


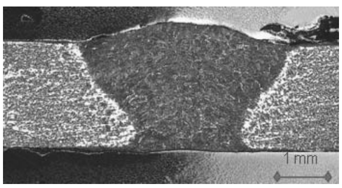
Figure 4. experimental setup

on the welding process. The processing head was mounted at a hexapod robot, which has very high positioning accuracy (figure 4). The setting angle α was constant at 38°. This is the smallest possible value with this setting. Most important varied parameters are listed in table 1.

Table 1. most important varied process parameters

Parameter [Unit]	Value or Range
Laser beam power [W]	0-550
Speed [cm/min]	40-150
Process gas volume flow rate [l/min]	0,15-1
Distance plasma torch-work piece [mm]	3-10
Focal position [mm]	0-10
Sheet thickness [mm]	2 and 4
Setting angle β_L [°]	3 and 19

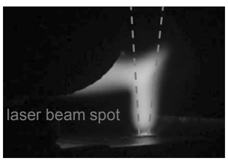
3. Results and Discussion



Best results on "plasma only" test series, micrograph shown in figure 5, were achieved by using following parameters:

- Current: 150 A
- Welding speed: 50 cm/min
- Process gas volume flow rate: 0,4 l/min
- Distance plasma torch to work piece: 7 mm

Figure 5. interactions observed between arc and laser beam on steel



Next interactions between arc and laser beam were investigated. Numerous combinations of parameters were analyzed. The focus of those test series was the detection of interactions between TIG arc and laser beam on steel materials and the investigation of correlations between different factors, like arc current, laser beam power, process speed etc. An influence of the laser beam on the TIG arc has been observed, as shown in figure 6.

Figure 6. interactions observed between arc and laser beam on steel

In studying the behavior of the arc during the variation of feeding rate and the arc current at different laser beam powers a high speed camera has been used. This camera had a frame rate of 10,000 frames per second. In figure 7 is the influence of different laser beam powers on arc current of 60 and 90 A at a constant feeding rate of 30 cm/min represented. In this process the arc has been trailed by electrode. The laser beam has been directed straight down to the sheet specimen and focused on the weld puddle caused by the arc.

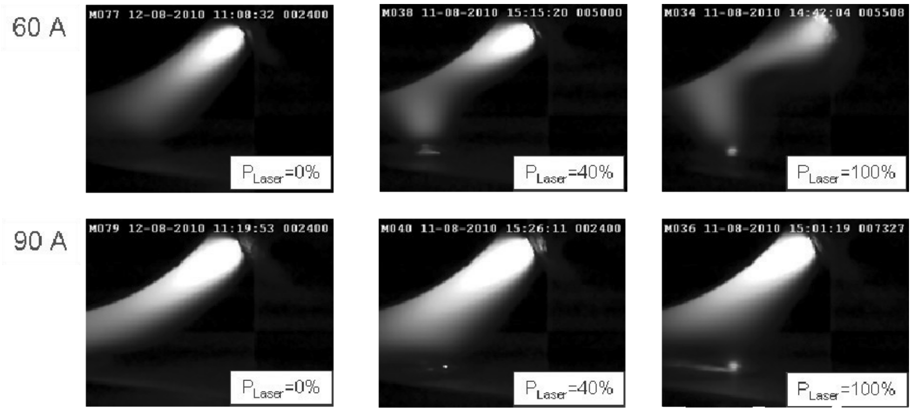


Figure 7. interactions observed between arc and laser beam in dependence of arc current by varying the laser beam power (unvaried parameters: welding speed: 30 cm/min; process gas volume flow rate: 8 l/min, distance torch to work piece: 4 mm; P_{Laser} = 100 % ≙ 300 W)

In the experiment without the laser light at a current of 60 A was observed that the arc falls angular to the rear. With increasing laser power, the arc is always more in a horizontal position, bends and enters almost coaxially with the laser beam on the specimen surface. As seen in the experiments with a larger current of 90 A, this effect decreases with increasing current. A possible reason for that is probably that the arc becomes more dominant by increasing of the current. As a result reduces the influence of the laser beam on the arc decreases by increasing arc current.

Also the dependence of interactions on welding speed has been investigated. In figure 8 is the influence of different laser powers at feeds of 30 and 50 cm/min at a constant arc current of 60 A shown. In this figure it is obviously that the arc at a larger feed is drawn clearly in the length. As already shown in the figure 7, the curvature of the arc increased with increasing laser power. This effect seems to subside at a larger feed. With a feeding rate of 50 cm/min, the arc is less curved than in an advance of 30 cm/min.

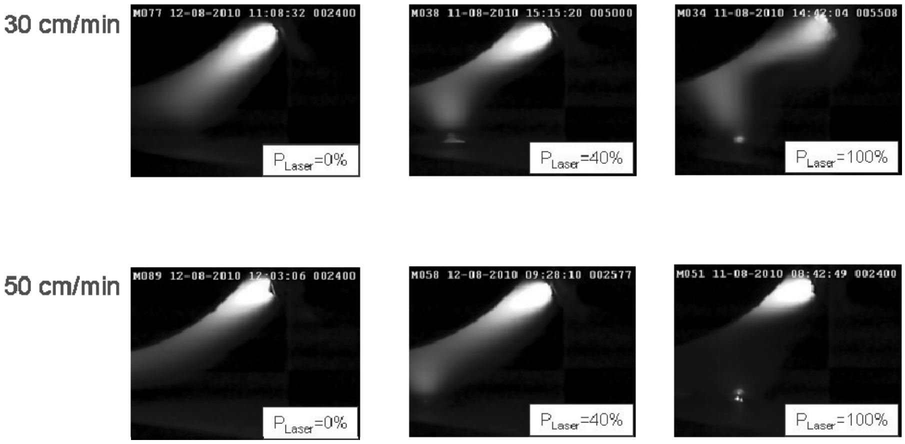


Figure 8. interactions observed between arc and laser beam in dependence of feeding rate by varying the laser beam power (unvaried parameters: arc current: 60 A; process gas volume flow rate: 8 l/min, distance torch to work piece: 4 mm; P_{Laser} = 100 % ≙ 300 W)

Using the result of PAW test series and newly achieved insights about arc-laser interactions as a reference for further investigations, new test series of the new developed plasma-laser-hybrid welding process were done. The main focus of hybrid process experiments was the effort to increase the welding speed and to stabilize the plasma arc. The power of the laser beam was varied in the range from 0 to 550 W. The focal position has been changed in a range 0 to +7 mm, which corresponded to a change of the beam spot in the range from 0.4 to 1.5 mm. The setting angle β_L has been adjusted at 19°. The result of those test series was an increase of welding speed to factor 2 compared to PAW. Figure 9 shows the behavior of welded seams caused by different laser beam power. An increasing penetration depth with increasing laser beam power has been observed.

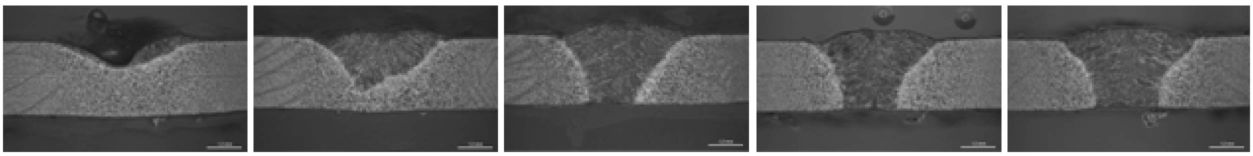


Figure 9. behavior of the joint caused by changing of the laser beam power (a) 0 W; (b) 220 W; (c) 330W; (d) 440 W; (e) 550 W (unvaried parameters: arc current: 150 A; welding speed: 100 cm/min; process gas volume flow rate: 0.8 l/min, distance torch to work piece: 8 mm, setting angle β_L 19°)

Same behavior has been observed after changing the setting angle β_L from 19° to 3°, as represented in figure 10. Obviously there is some kind of threshold intensity of the laser beam. An exceeding of this intensity makes the PAW process much more efficient and allows a reduplication of the welding speed compared to the conventional PAW process. But the increase of the penetration depth can not only be caused by increased beam power. This behavior confirms the hypothesis of the interactions between laser beam and arc. Further it could be observed that this effect has become stronger by defocusing of the beam spot.

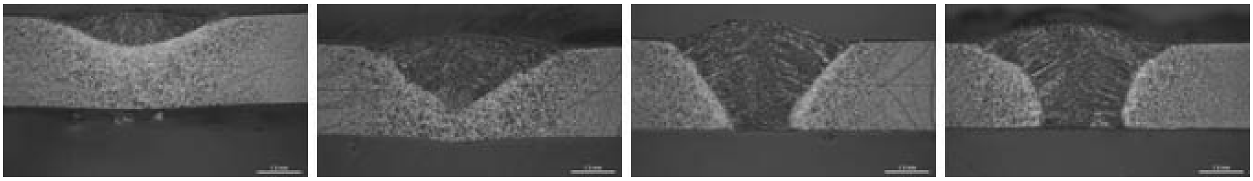


Figure 10. behavior of the joint caused by changing of the laser beam power (a) 0 W; (b) 220 W; (c) 330W; (d) 440 W (unvaried parameters: arc current: 150 A; welding speed: 100 cm/min; process gas volume flow rate: 0.8 l/min, distance torch to work piece: 8 mm, setting angle β_L 3°)

Further the sheet thickness has been varied. Welding experiments were also done on 4 mm sheets. In this case the depth of penetration has been investigated. In figure 11 is the behavior caused by combination of plasma arc with laser beam shown. The current of the plasma arc has been adjusted to 150 A. The feeding speed was 25 cm/min. The process gas volume flow rate was also constant as well as other process parameters accept of the laser beam power. The increase of the penetration depth is higher than it could have been induced just by increased energy input per unit length by adding the power of the laser beam. Obviously there is a focusing effect caused by interactions between plasma arc and laser beam.

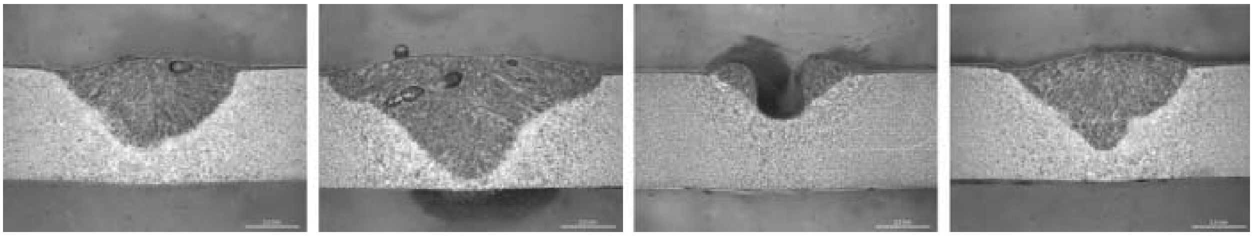


Figure 11. behavior of the joint on 4 mm sheets caused by changing of the laser beam power (a) 0 W; (b) 440 W; (c) 0W; (d) 440 W and the feeding speed: a), b) 20 cm/min, c), d) 25 cm/min (unvaried parameters: arc current: 150 A; process gas volume flow rate: 0.4 l/min, distance torch to work piece: 8 mm, setting angle β_L 19°)

An approach to the explanation of this effect is absorption of the laser power by the plasma arc. This improves and enhances the ionization effect, resulting in the reduction of the arc diameter. This theory confirms the statement that the opto-galvanic effect is responsible for focusing the arc. The opto-galvanic effect describes an increasing or decreasing of the conductivity of a gas discharge when it is irradiated by resonant light, so light, in which the frequency to that of an atomic transition in the discharge complies.

Other publications point to the influence of metal vapor produced by the laser. Thereby causes the laser-induced metal vapor a locally higher electric conductivity of the plasma arc. The practical benefit of reducing the cross section of the arc is an increase in efficiency, allowing higher welding speeds.

In this constellation of laser beam and plasma arc is a new process, which is not used in the industry and small and medium-sized enterprises, however, a technically and economically attractively process. Welding speeds could be increased from 50 cm/min to 100 cm/min. This represents an increase of 100 % with similar quality standards. At this point to mention is that the power of the plasma-arc of about 4500 W by coupling with a laser beam of 300 W results to an increase in heat input of less than 10 %. Adequate welds with lower quality requirements were achieved even up to speeds of 110 cm/min.

The study examined the influence of variables such as laser power, plasma gas flow rate, focus position, and various welding angle and welding directions based on test welds on S235JR steel sheets with 2 and 4 mm thickness. The metallographic investigations were accomplished on microsections, revealed remarkable differences between a hybrid and a weld seam, which was produced by a pure plasma arc. To observe the influence of each parameter on the overall process, the statistical software Minitab was used. Also was found that the hybrid process is susceptible to disturbances. Minimal displacements in the angle between the laser and plasma spray or wear of the plasma nozzle affect the result significantly.

In this work a Nd-YAG solid-state laser with a maximum power of 4400 W was used cut back accordingly. Approaches for further study are to analyze the interactions between the plasma arc and a laser beam with different excitation wavelength or power. In particular, low-powered lasers are for the overall process economically viable and represent a challenge in the practical implementation.

More interesting ideas for research projects would be an implementation of this project on the joining of two sheets. Other interesting approaches to research would be to implement this Project on the joining of two sheets. This would not only be an ability to bridge gaps to be examined criterion that needs further description, the possibilities for the design of welded joints, for example, fillet, lap joint provide new challenges in the steel processing.

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