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Hybrid welding of supermartensitic stainless steel

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1 Abstract

Economical aspects in the offshore industries lead to new materials and due to these materials to new production technologies. One of these technologies is the hybrid welding process. Compared to laser welding, the combination of the laser and one conventional welding process (e.g. MIG) offers many advantages like wider gap bridgeability, enhanced process stability and higher welding speed.

In this work, two different grades of supermartensitic stainless steels have been welded with newly developed matching filler wires. All experiments were carried out with a CO_2-Laser of up to 12 kW combined with a Dalex Vario MIG-machine of up to 450 A. A special working head was developed, which integrates all needed components, such as crossjet, gun, etc. Different set-up concerning the position of MIG gun to the laser beam and angle of the gun were tested.

The seam geometry could be varied in a specific way to design seam geometries on demand. Mechanical and technical properties were measured as well as metallographic examinations were done. The results are very promising and offer the industrial application of that welding technology in the near future.

2 Keywords

Hybrid welding, CO_2-Laser, Supermartensitic Stainless steel, Laser-MIG-Welding

3 Introduction

The Hybrid welding process is defined as the coupling of the laser beam welding with a conventional welding process, such as the MIG-welding process. This process has, as arc augmented laser beam welding, been investigated since the first experiments of Steen in the seventies [1]. Research work has been done concerning the potential and advantages of the process combination [2,3,4]. The potential is to increase the weld bead penetration, the width and the weld speed.

The laser beam process with its characteristic high and focused power density leads to deep and narrow welds. The comparably wide process zone of the arc process enables a better gap bridgeability and reduces the joint preparation effort in this way.

Laser-MIG welding causes wider and deeper beads at higher welding speeds as compared to laser welding [5,6]. Higher welding speeds lead to less heat input (at constant power).

The two processes can either be coupled in one process point or be combined in a serial way. Only the coupling of both is called Hybrid welding process although in most cases the “focal point” of both processes is not exactly the same. There are different statements in literature concerning the optimum positioning regarding the deepest penetration, stabilized process, etc. To investigate the influence of the main parameters, i.e. arc and laser power, on the bead geometry, one single “focal point” was used in the following experiments.

The principle set-up, including the measuring equipment, is shown in Figure 1.

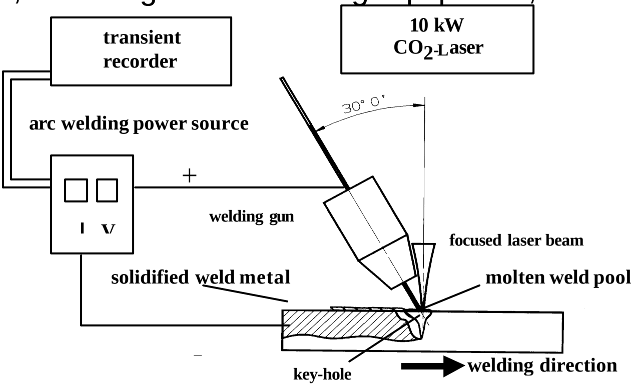


Figure 1: Principle set-up of the experiments

The laser is leading the MIG-gun, which is feeding the shielding gas. A transient recorder is recording the actual current and voltage with up to 100 kHz.

A 10 kW CO_2-Laser with a 300 m focal length (focus diameter 0,8 mm) was coupled with a 400 A Dalex MIG-machine. The stick out was 15 mm. All experiments concerning the seam geometry were welded at a welding speed of 1.8 m/min. A standard gas mixture of Helium (75%), Argon (23%) and Oxygen (2%) was used at 30 l/min.

The gas mixture has a special importance for hybrid welding. On the one hand the laser process is significantly influenced by the occurring plasma above the key hole. The plasma density should be as much minimised as possible to avoid a shielding effect for the beam (CO_2-Laser with λ = 10,6 µm). In most cases, due to its high ionisation potential, Helium is used to reduce the shielding. On the other hand, the MIG process is usually applied with Argon with a small content of Oxygen or carbondioxide as a shielding gas. The two different gases implement the request to find one suitable mixture for the hybrid welding, which is the aforementioned for these experiments. Laser beam welding with high power values is indicated by the deep penetration effect. The occurring key hole is appearing with a vaporising of material. This vaporised material, with its low ionisation potential, is supplying good conditions for the arc and is stabilising it. Furthermore the weld pool caused by the MIG-process has a positive influence on the laser process. The laser does not need to melt the surface but it is acting in the preheated molten pool of the MIG-process.

4 Experimental work

During these experiments the technical and "process sided" conditions for Laser-MAG-Welding of austenitic and supermartensitic stainless steel have been carried out. These experiments should give the basis for an industrial application of the hybrid welding process on stainless steels.

4.1 Working head

An important part of every laser based welding process is the working head. For the hybrid welding process the working head has to combine the parts of the laser and the GMAW-process. The newly developed head integrates all components, such as cross-jet, focussing mirror, welding torch, four-wheel drive and anti-collision-set and enables accurate and reproducible positioning of the processes. It additionally enables the adjustment of both processes to each other.

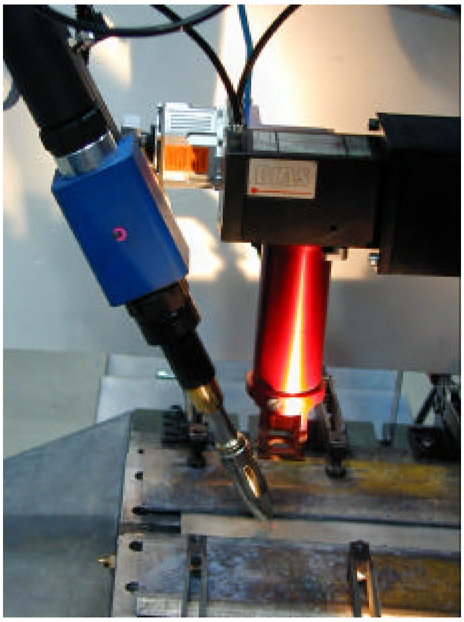
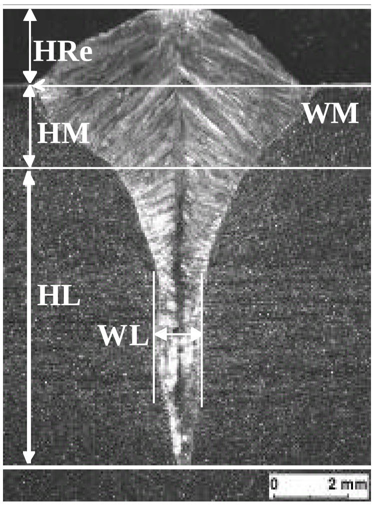


Figure 1: Working head for hybrid welding

4.2 Evaluation system

The different shapes of the hybrid welded seams require an adapted evaluation system. This system allows the influences of both single processes on the bead geometry to be evaluated separately.



HRe:	Height Reinforcement
HM:	Height MIG part
HL:	Height Laser part
WM:	Width MIG part
WL:	Width Laser part

Figure 2: Evaluation system for hybrid welded seams

4.3 Welding parameters and materials

All experiments have been done with a 10 kW CO_2-Laser (Rofin Sinar RS10000) with a 300 mm focal length. The GMAW-part of the process was supplied by a 400 A Dalex Vario MIG-machine with a special machine torch built by Abicor Binzel. The shielding gas, a Ar/He/O_2 mixture, was fed through the torch. All other parameters are shown in table 3.

P_L	v_S	I	U	v_D
4-9 kW	1.8 m/min	230-290 A	19-28 V	9-13 m/min

Table 3: Welding parameters

Two sets of experiments have been performed. One on austenitic stainless steel to validate the functionality of the working head and to carry out the influence of various process parameters on the bead geometry. The second set was done on supermartensitic stainless steel, to evaluate the weldability of this material with the hybrid welding process. The chemical composition of both base and filler material are listed in table 4.

Base Material	C	Si	Mn	N	Cr	Mo	Ni
X2	0,03	1,00	2,00	≤ 0,11	16,5-18,5	2-2,5	10-13
X80	0,15	0,13	1,76	0,011	11,46	1,38	4,66
Filler wire							
1.4302 - X2	0,05				19		9
1.4418 - X80	0,013	0,52	0,67	0,003	12,37	2,65	6,37

Table 4: Chemical composition of base and filler material

5 Results

5.1 Bead Geometry

One advantage of hybrid welding is the better gap bridgeability, which is mainly influenced by the width of conventional part, the MAG-penetration and the width of the laser part of the bead. The dependence of them versus the laser and MAG power should show the possibilities to design the bead geometry.

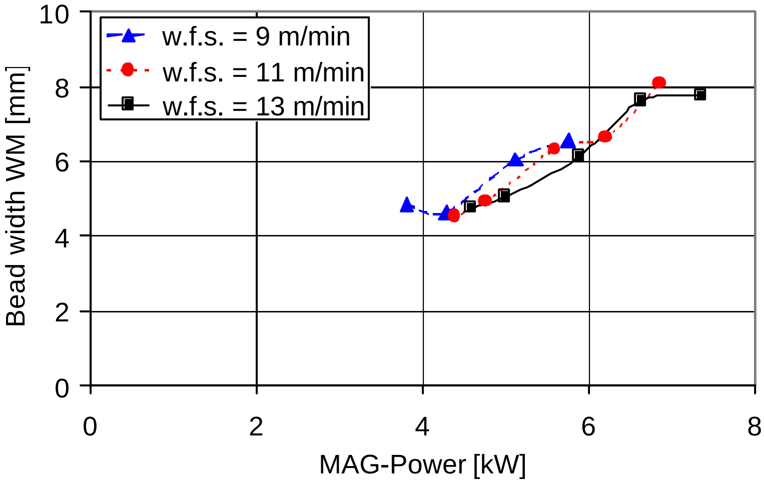


Figure 5: Bead Width versus MAG-Power, P_L = 4 kW

Figure 5 shows that an increasing arc power leads to wider beads. The arc power was mainly increased by a higher voltage, that implements a wider arc (due to the shift from short circuit to spray transfer mode) and this way a wider bead.

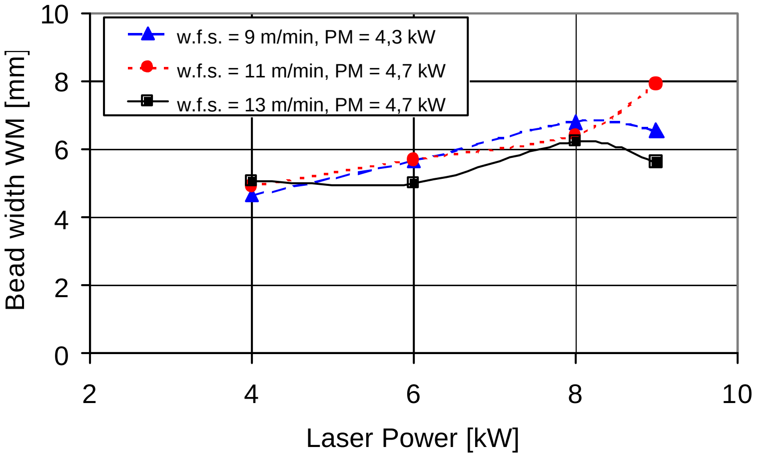


Figure 6: Bead Width versus Laser Power

The influence of the laser power on the width of the conventional part only results from the increased overall energy input, which rises with higher laser power (Fig. 6).

To bridge a gap, the penetration of the bead width is as important as the width of the bead. As Figure 7 illustrates, the wider bead is correlated with a drop of the MAG penetration due to the change from short circuit to spray transfer mode. The smaller droplets with less kinetic energy lead to less penetration. The laser power has no effect on the MAG-penetration.

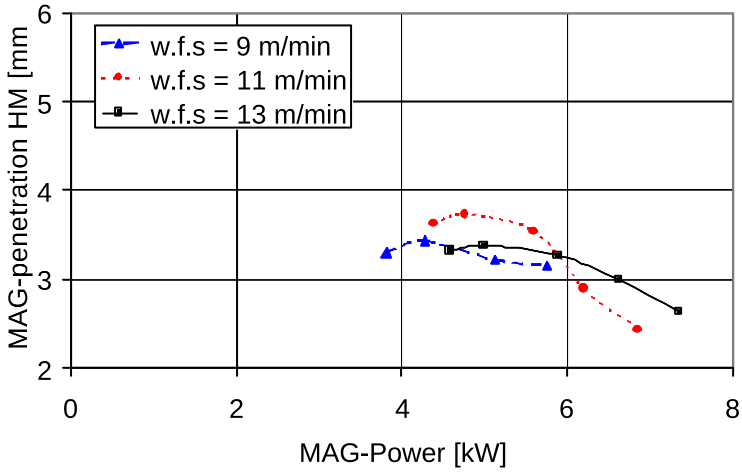


Figure 7: MAG penetration versus MAG power, P_L = 4 kW

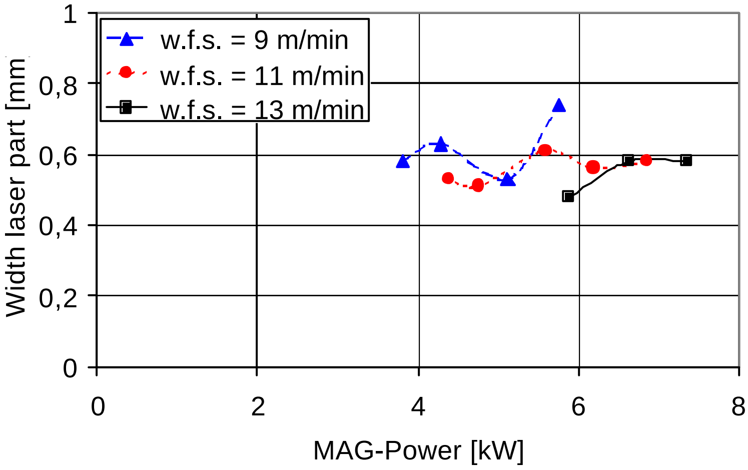


Figure 8: Width Laser Part versus MAG-Power, P_L = 4 kW

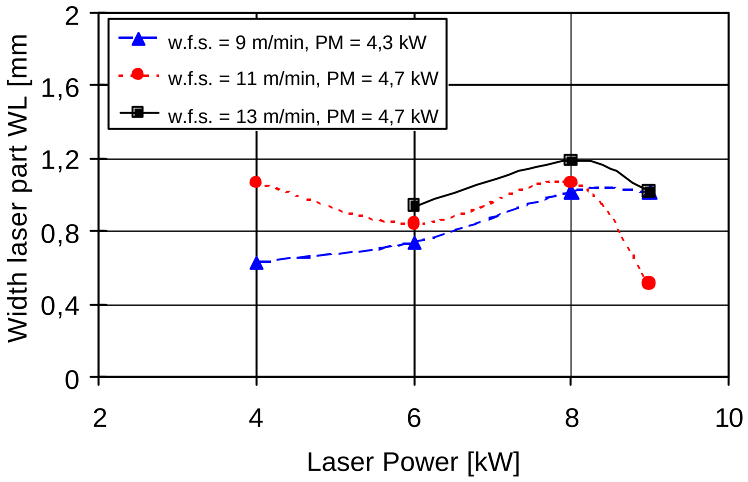
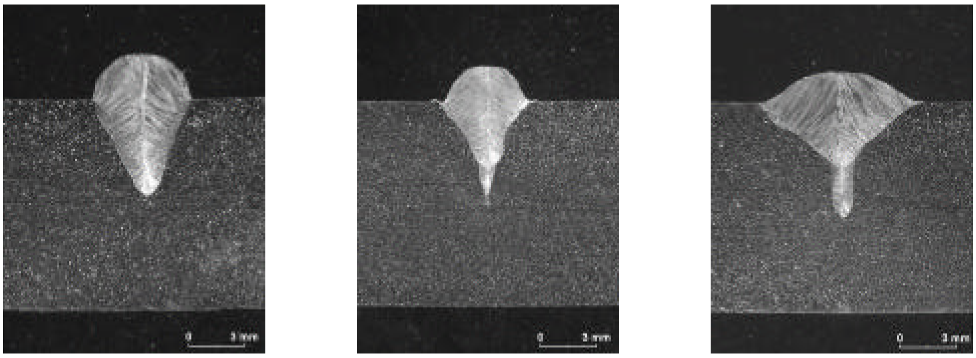


Figure 9: Width Laser Part versus Laser Power

Besides the MAG width, the width of the laser part is important to bridge gap over the hole plate thickness. Both process powers do not have any influence on the bead width of the laser part (Fig. 8,9). This geometry is only influenced by the beam shape which can only be change by a different focal length or position.

Figure 5-9 show the possible variation, which can be achieved with the hybrid process. This process offers the chance to design bead geometries on demand.

The three cross sections show the variations which occur due to the shift from the short circuit to the spray transfer mode.



Number of Short Circuits: 173 Hz 89 Hz 19 Hz

Figure 10: Cross sections with different number of short circuits, P_L = 4 kW, v_S = 1,8 m/min

5.2 Weld Properties of Supermartensitic Stainless Steel

The supermartensitic stainless steel was welded with laser power of P_L = 7,5 kW. Current was 144 A at 15,8 V and 7 m/min wire feed speed. The gas mixture was again Helium, Argon and Oxygen at 30 l/min.

All experiments have been welded with the same set-up as the weldment on the austenitic steel as shown in Figure 1.

All weldments have been done at 2.5 m/min welding speed, which is a good increase compared to the normally used speed during laser beam welding (~ 1.5 m/min). The test has been done in the as welded and in a tempered condition (640°C, 10min).

5.2.1 Hardness

The base material shows hardness values from 311 to 354 HV10. The high deviation of ±20 HV10 and the high hardness level may result from the cold deformation process of the weld component. The hardness in the heat affected zone (292 – 343 HV10) and in the weld seam (335 – 337 HV10) is compared to theses values in an equal range.

The post heat treatment reduced the hardness to acceptable values for these materials. The base material hardness decreased to 268 – 290 HV10. The hardness in the heat affected zone and in the weld seam reached valid values (critical value is <350 HV10), respectively 269 – 320 HV10 and < 320 HV10.

In both conditions the hardness is lower than expected values from laser beam welding, which may result from the additional heat source of the MAG process. It increases the heat input, prolongs the cooling time and avoids hardening of the seam. The slightly higher values in the weld seam may result from the overmatching filler wire with it's higher strength.

5.2.2 Strength

The proof strength and the tensile strength have been measured in the as-welded and in the tempered conditions.

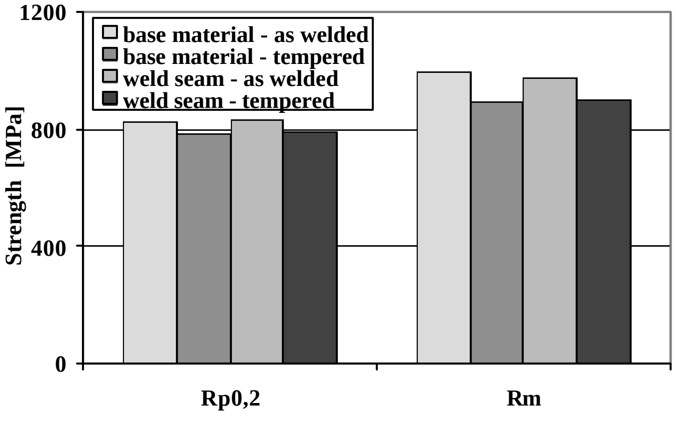


Figure 10: Proof stress and tensile strength

As shown in Figure 10, the strength of the weld seam matches the strength of the parent material. The tempering reduced both values to lower levels, which are still above the requested values ($R_{P0,2}$ = 550 MPa). Furthermore, the variation is smaller in the tempered condition.

The mechanical properties are in the requested range. No invalid overmatching is occurring neither in hardness nor in strength. The used filler wire is suitable to weld these materials with the hybrid welding process.

6 Conclusion

The hybrid welding process has a good potential to extend the field of applications of the laser technology. The combination of the two processes and the occurring synergy effects offer the possibility to design bead geometries on demand. The supermartensitic stainless steel can be hybrid welded with good results in hardness and strength. The results of the experiments show the potential of the hybrid process for an industrial application in the near future.

7 Acknowledgements

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