

Process Stability and Design of Seam Geometry during Hybrid Welding

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Abstract

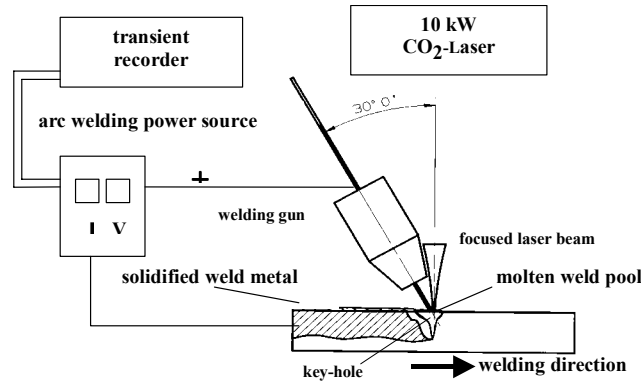
Economical aspects in the offshore industries lead to new materials and due to these materials to new production technologies. One of these technologies is the hybrid welding process. Compared to laser welding, the combination of the laser and one conventional welding process (e.g. GMAW) offers many advantages like wider gap bridgeability, enhanced process stability and higher welding speed. Hybrid welding allows the geometrical design of weld seams on demand. The paper shows the results of hybrid welding experiments with austenitic stainless steel and supermartensitic 13%Cr steel. Tensile tests and hardness measurements were carried out. All tests have been performed in the as-welded and in the post weld heat treated conditions. The results show a very good behaviour of the hybrid welded samples with seam properties close to the properties of the base material. It is concluded that the hybrid welding process has the potential to be implemented in industrial production in the near future.

1 Introduction

The Hybrid welding process is defined as the coupling of the laser beam welding with a conventional welding process, such as the GMAW-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 the better gap bridgeability and reduces the joint preparation effort in this way. Laser-GMAW welding causes wider, deeper beads at higher welding speeds [56]. Higher welding speeds lead to less heat input (at constant power), less thermal distortion and thereby less reworking of the components. 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, stabilised 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 GMAW-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 CO₂-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 should be as much minimised as possible to avoid a shielding effect for the beam (CO₂-Laser with $\lambda = 10,6 \mu\text{m}$). In most cases, due to its high ionisation potential, Helium is used to reduce the shielding. On the other hand, the MAG process is usually applied with Argon with a small content of Oxygen or carbon-dioxide 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 MAG-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 MAG-process.

2 Experimental work

Aim of the experiments was to investigate the different interactions between the main welding parameters such as arc and laser power and the resulting bead geometry. These results should enable designing seam geometry's on demand. They were carried out on austenitic stainless steel in bead on plate weldments. Plate thickness of the austenitic steel was 10 mm, and of the supermartensitic steel 6 mm. Both filler wires were matching materials of 1,2 mm diameter. [Table 2](#) is showing the chemical composition of the base and filler materials. Regarding to the aim of the experiments only few of the parameters were varied. [Table 3](#) presents the welding parameters, which were used during the experiments.

Table 2: Chemical composition of base and filler material for both sets of experiments

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	0,01 3	0,52	0,67	0,003	12,37	2,65	6,37

Table 3: Welding parameters for the first set

		Arc Power = mean welding current x mean arc voltage														
		w.f.s = 9 m/min: I _m ~ 230 A					w.f.s = 11 m/min: I _m ~ 260 A					w.f.s = 13 m/min: I _m ~ 290 A				
		Set arc voltage					Set arc voltage					Set arc voltage				
		4	19	21	24	26	28	19	21	24	26	28	19	21	24	26
Laser power [kW]	6	19	21	24	26	28	19	21	24	26	28	19	21	24	26	28
	8	19	21	24	26	28	19	21	24	26	28	19	21	24	26	28
	9	19	21	24	26	28	19	21	24	26	28	19	21	24	26	28

w.f.s : wire feed speed

I_m: mean arc current

3 Effect of the welding parameters on the bead geometry

To validate the hybrid welded seams a hybrid evaluation system was set-up, Fig. 4. This system allows to separate the single process areas in the hybrid seam.

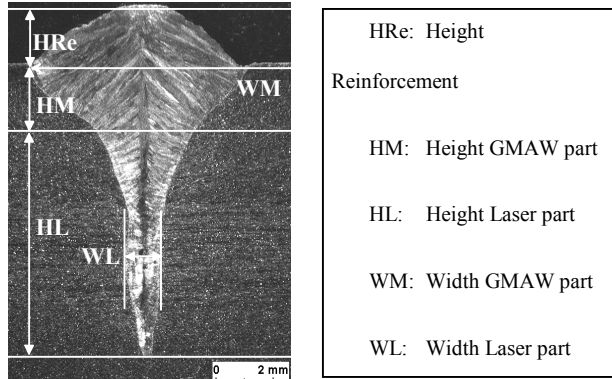


Figure 4: Evaluation system

The bead width, which is indicated by the values WM and WL for the MAG and Laser part, respectively, is influenced by both the arc and laser power. A wider bead is able to bridge a wider gap and this leads to lower joint preparation requirements.

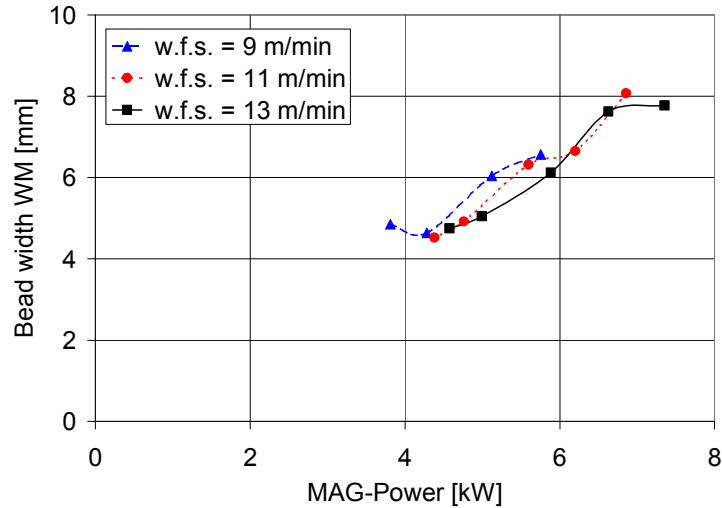


Figure 5: Bead width versus MAG-Power, $P_L = 4$ kW

Increasing arc power at constant wire feed speed (w.f.s) and laser power, increases the bead width WM, Fig. 5. This rise has a maximum with 9 m/min and 11 m/min w.f.s. With 13 m/min it stays unchanged on the maximum with still increasing arc power. The increase of the arc power is realised with increasing arc voltage (w.f.s is constant as shown in Table 3). This leads to a wider arc, which enlarges the wetting zone. After reaching the maximum, an additional rise of arc power does not widen the wetting zone, due to the insufficient energy in the outer areas.

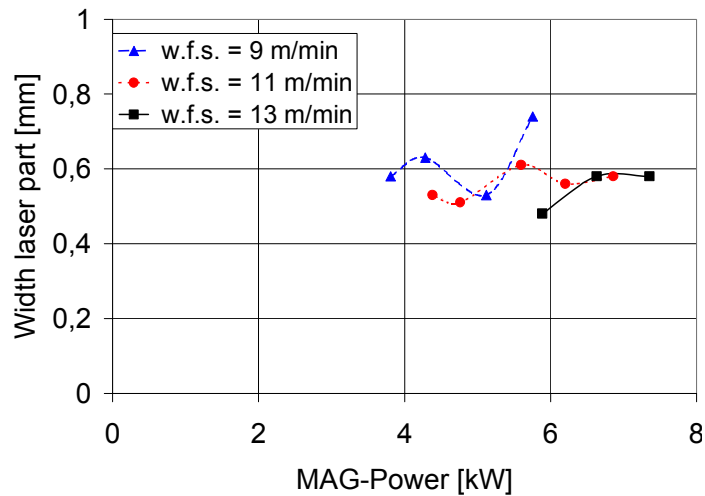


Figure 6: Width laser part versus MAG-Power, $P_L = 4$ kW

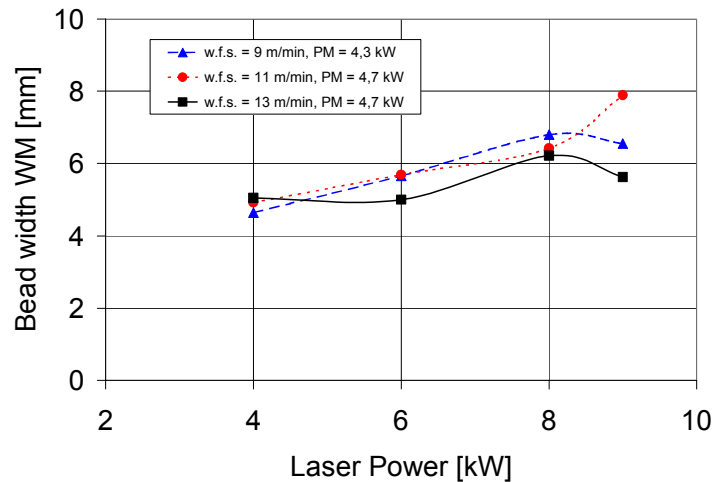


Figure 7: bead width versus laser power

The width of the laser part WL is not effected by a change of MAG-power, [Fig. 6](#). This results from the beam shape which is not influenced by the arc power.

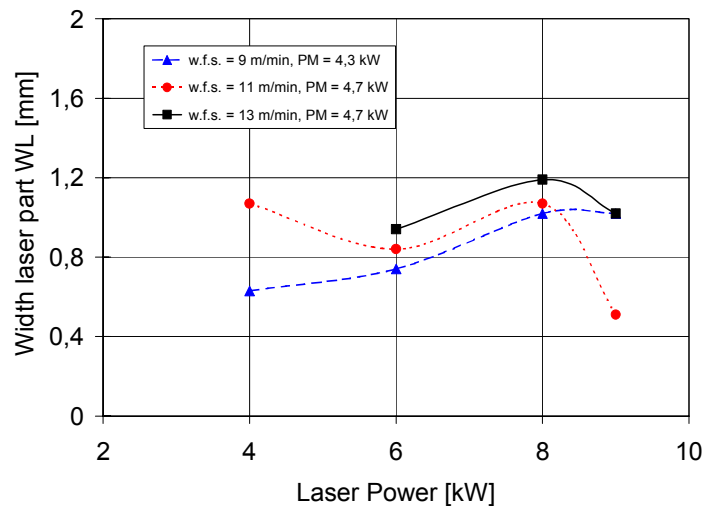


Figure 8: Width laser part versus laser power

Both the MAG- and the Laser-part width are slightly increasing with higher laser power as shown in [Figure 7](#) and [Figure 8](#). Higher laser power introduces more energy into the work piece and widens the weld pool. The effect on WL is less because of the constant shape of the key hole at different laser powers, but higher power is implementing more heat input and so widen the weld pool a little. The drop at 9 kW is resulting from an increased plasma shielding. Accompanied with the beam width is the bead reinforcement, [Fig. 9](#), which is often to be minimised to reduce the reworking effort.

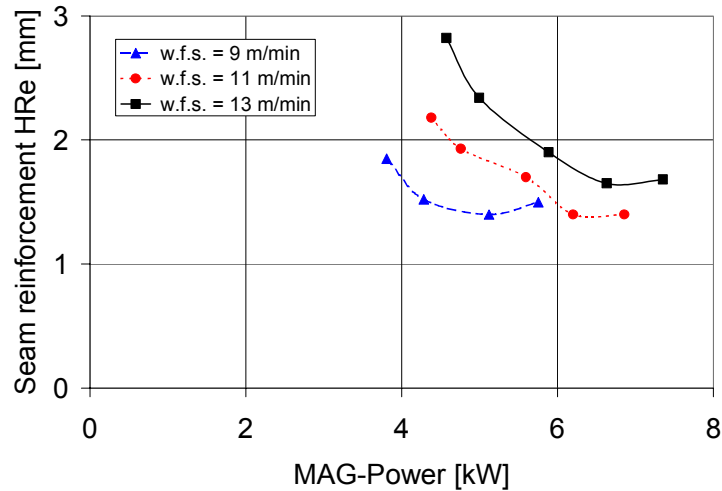


Figure 9: Seam reinforcement versus MAG-Power, $P_L = 4$ kW

As known from the single MAG-welding process, the bead reinforcement is slightly decreasing with increasing arc power. The reason is the change in the metal transfer mode to the spray transfer.

3.1 Conclusion of first group of experiments

The bead width is, in both cases WL and WM, influenced by a change of laser power. Increasing laser power leads to wider beads. Only at higher values the arc power is influencing, enlarging WM and reducing HRe.

Reducing the cost by designing the seam geometry and this way reducing the reworking effort is one possibility. In many cases a change in the used material to cheaper or better ones is the second one. Supermartensitic stainless steel have advantages concerning the cost side, but disadvantages concerning the manufacturing side comparing to Duplex or Super Duplex steels. To produce e.g. pipes an improved welding technique has to be developed, which guaranties desirably good seam properties equal to the base material.

4 Mechanical properties of supermartensitic stainless steel

The supermartensitic stainless steel was welded with laser power of the 10 kW CO₂-Laser of $P_L = 7,5$ kW at 2.5 m/min welding speed. Current was 144 A at 15,8 V and 7 m/min w.f.s.. 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).

4.1.1 Hardness

The base material shows quite high hardness values from 311 to 354 HV10 in the as-welded condition. The high range of nearly ± 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 these values in an equal zone. 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 (269 – 320 HV10) and in the weld seam (< 320 HV10) reached valid values (critical value is <350 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 avoid hardening of the seam. The slightly higher values in the weld seam and the heat affected zone may result from the overmatching filler wire with it's higher strength.

4.2 Strength

Concerning the strength, the proof stress and the tensile strength have been measured. These tests have also been performed in the as-welded and in the tempered conditions.

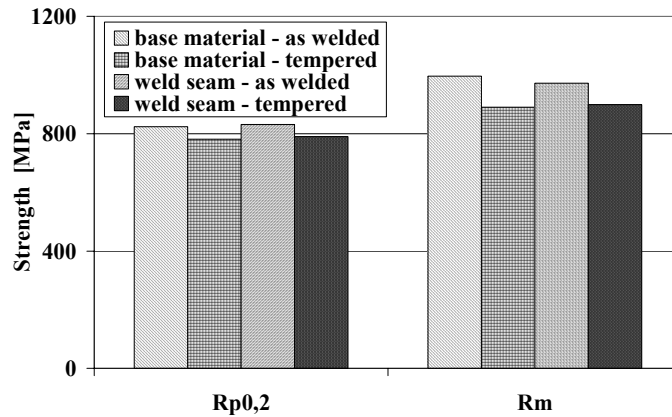


Figure 10: Proof stress and tensile strength

As shown in Figure 10 the stress and the strength do not vary much between the base material and the weld seam. No overmatching is occurring. 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 and the materials are tranquillised.

4.2.1 Conclusion on the mechanical properties

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.

5 Conclusion and outlook

The influence of the process parameters has been investigated. The hybrid welding process enables a design of weld seam geometry's on demand, which should be investigated on practical samples with different gaps and gap forms. The joint preparation and the reworking of the components can be reduced in this way. Supermartensitic stainless steels are well weldable with the hybrid welding process. The mechanical properties are in a good range. Hybrid welding is a

potential enhancement of the laser beam welding and will be applied on some industrial sites in the near future.

6 Literature

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