Lasers in Manufacturing Conference 2017

Laser beam submerged arc hybrid welding for thick metal sheets

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Abstract

The Laser beam Submerged Arc Hybrid welding technique (LB-SAW Hybrid) is a suitable welding process for joining thick metal sheets of up to 50 mm plate thickness in double-sided single pass technique. Especially in pipeline manufacturing, LB-SAW Hybrid has the potential to replace the currently used time consuming conventional welding processes. However, despite the LB-SAW Hybrid being under constant research, the behavior of this welding process is still not completely understood.
This contribution presents the latest welding results which were achieved with the LB-SAW Hybrid technique on metal sheets with a plate thickness of 40 mm. The influence of the inclination angle of the laser optics and the SAW-torch regarding the penetration depth as well as the metallurgical composition of the hybrid weld metal are shown. Due to the hybrid process, it was possible to achieve an increase in the maximum reachable penetration depth of several millimeters compared to a serial process setup using the same power. Additionally, the intermixing of the alloying elements in the transition area between SAW- and laser beam-dominated weld seam area are demonstrated in this contribution. Furthermore, the microstructure of the hybrid weld metal is presented and discussed.

Keywords: Welding ; Hybrid ; Laser beam ; Submarged arc

1. Motivation

Welding of thick-walled sections in semi-finished products or constructions is a challenging process. In the fields of off-shore wind power plants as well as pipeline production, plate thicknesses up to 50 mm and even more are to be processed. At present, this joining task is done implementing the conventional welding methods, such as the submerged arc welding process (SAW). A numerous weld passes are necessary to fill the groove, Fig. *1* (left).

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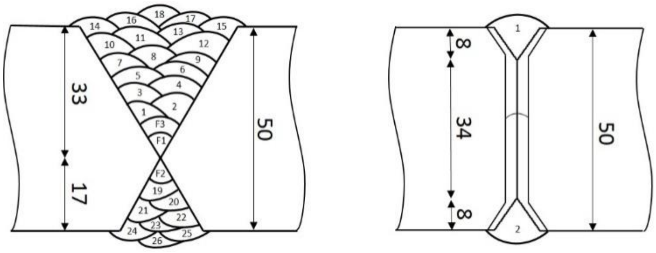

Fig. 1. (Left) SAW process; (Right) LB-SAW Hybrid process

In addition to the risk of inter-pass discontinuities, high thermal load on the material, labor-intensive and time-consuming activities represent a negative aspect in economical and engineering perspectives. The combination of the submerged are welding with a laser beam to a hybrid welding process opens up the possibility of accomplishing this joining task by means of a single pass-double sided joint design, Fig. *1* (right). Less material removal, less bevel preparation work and therefore less quantities of filler material are needed whereby.

2. State of the art

The laser beam submerged arc hybrid welding (LB-SAW Hybrid) is a novel welding process which has been used successfully in laboratory scale for a few years. Plate thicknesses of 36 mm could be joined by means of a CO_2-laser combined with a SAW process, (Reisgen, et al., 2012). After that the maximum plate thickness was increased to 50 mm using a solid state laser, (Reisgen, et al., 2014) (Reisgen, et al., 2016), Fig. *2*.

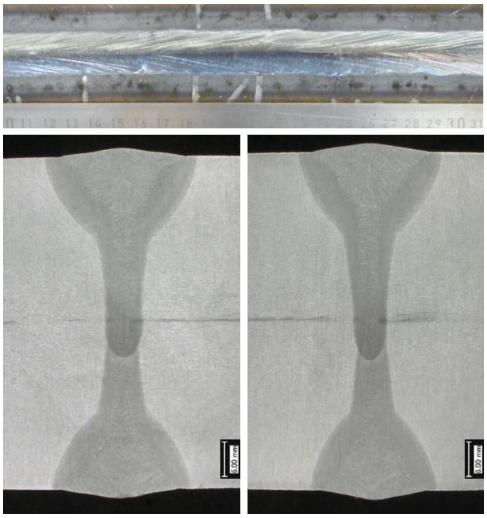

Fig. 2. LB-SAW Hybrid, plate thickness: 50 mm, *(Reisgen, et al., 2016)*

However, the strongly differing values of notch impact properties for the various regions of the weld were found striking. An average of 220 J notch impact strength was determined in the laser beam dominated area, while the same was roughly 90 J in the submerged arc welding dominated area, (Reisgen, et al., 2012), resulting in the formation of a metallurgical notch in the transition region between the two mentioned areas. To improve mechanical properties of the weld metal, different hybrid welding head set ups were practiced. A hybrid weld metal characteristics, the one having the same chemical analysis both in submerged arc welding and laser beam dominated areas, was thought to help a constant mechanical properties in the mentioned areas. In different stages of process development, SAW torch and laser beam angle were changed, creating different process distances. With a laser beam perpendicularly flashed, SAW torch angle changed from 20° to zero, the depth pf penetration got 3 mm dipper in SAW dominated area, however, no hybrid weld metal was deposited.

3. Welding Setup

Fig. *3* shows schematically the geometrical arrangement of the welding head components with which welding tests were carried out in this work.

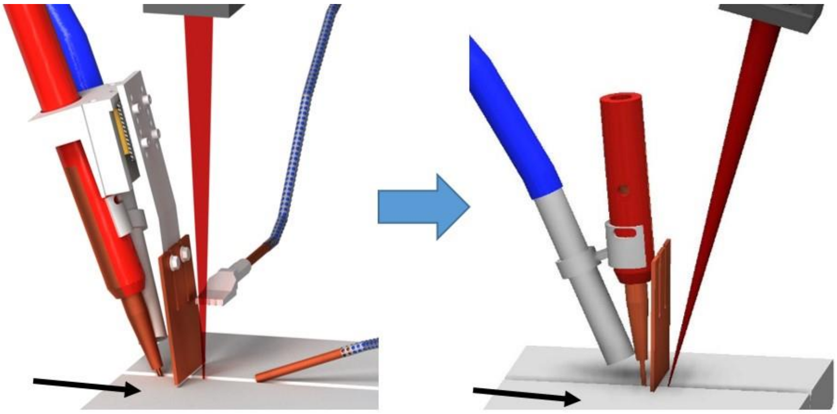

Fig. 3. (Left) Pervious set up; (Right) New set up

The system shown in the left-hand part of the sketch was already used (Reisgen, et al., 2016) (Reisgen, et al., 2017). In the recent trails, the SAW torch has an angle of incidence of 5° of the component surface, vertically. The laser beam strikes the component surface at an angle of 14°. There is still a separating plate between the two components. The process gas nozzle was completely removed with in this setup. The base metal used for the series of tests is S355 M (construction steel with a minimum yield strength of 355 N/mm²) having a very low carbon content, Table 1.

Table 1. Chemical composition of the base metal, S355 M

Element	C	Si	Mn	P	Cr	Ni	Cu
[%]	0.033	0.33	1.52	0.009	0.15	0.013	0.017

The thickness of the base metal is 40 mm with a bevel preparation of double V-groove. The groove angle was 70° while the root face height was 26 mm. There is no root opening. A schematic picture of the bevel preparation is shown in Fig. 4.

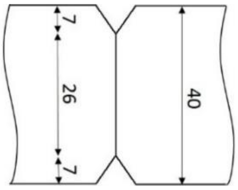

Fig. 4. Weld preparation LB-SAW Hybrid, plate thickness: 40 mm

For the welding trials an aluminate-basic flux with the designation ESAB OK FLUX 10.62, having an index of basicity equal to 3.2, was combined with a wire ESAB OK AUTROD 13.27, diameter 4 mm. This combination of flux and wire was chosen following the manufacturers' recommendation well suited for submerged arc welding of unalloyed construction steels, (Company, 2008). Concerning the optical setup, a 200 µm light guiding fiber and a lens with an aspect ratio of 2:1 is used, which leads to a mathematically determined focal diameter of 0.4 mm.

4. Results and discussion

The influence of the inclination angle of the laser optics (and obtained process distance from) regarding the penetration depth and the chemical composition of the weld metal will be investigated. The new hybrid welding head set up was practiced in which the angle between laser beam and work piece surface was increased from zero to 14° and the angle between SAW torch and work piece surface was put in approximately 5° to obtain a process distance equal to 19 mm, see Fig. 5. SAW welding parameters were 35 volt and 2.1 m/min wire feeding rate. The laser power was 16 kW. Welding travel speed was set as 0.6 m/min. To practice such changes and evaluate related results, welds A and B were deposited.

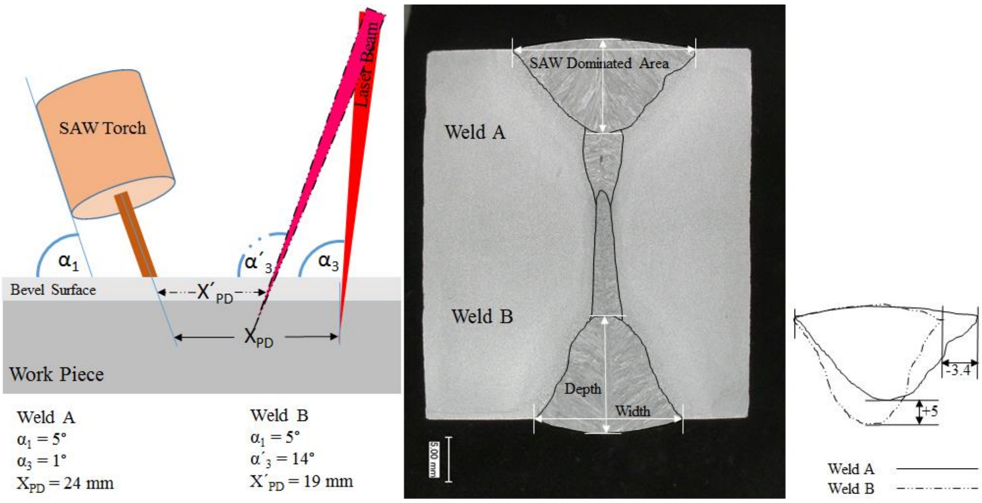

Fig. 5. (Weld A) None-hybrid weld metal; (Weld B) Hybrid weld metal

Geometrical measurements in the transverse cross section of welds A and B revealed that the width of weld seam in SAW dominated area decreased from 18.9 to 15.5 mm while the depth of penetration increased from 7.6 to 12.6 mm, changing laser beam angle. The biggest width in LBW dominated area was measured 4.6 mm in weld A and the same was 2.9 mm for weld B. The enlarged SAW dominated area in weld B, from 106.1 to 123.9 mm^2, is hoped to promise a chemical composition more close to LBW dominated area, see Table 2.

Table 2. Geometrical measurements of weld seams in cross section

Weld No.	SAW Depth of Penetration, [mm]	SAW Width, [mm]	LBW Depth of Penetration, [mm]	LBW Width, [mm]	Total Depth of Penetration, [mm]	SAW Area, [mm^2]
A	7.6	18.9	14.9	4.6	22.5	106.1
B	12.6	15.5	13.2	2.9	25.8	123.9

4.1. Chemical Analysis

To understand how much the chemical composition in different welds is, SAW and LBW dominated areas, chemical analysis were carried out. The assumption for a weld metal to be hybrid or not is having the same or close values of any single chemical elements in different areas subjected to probing. The closer these values, the higher the rate of intermixture between SAW and LBW dominated areas is, meaning that the wire and flux combination from SAW dominated area has influenced the LBW dominated area more.

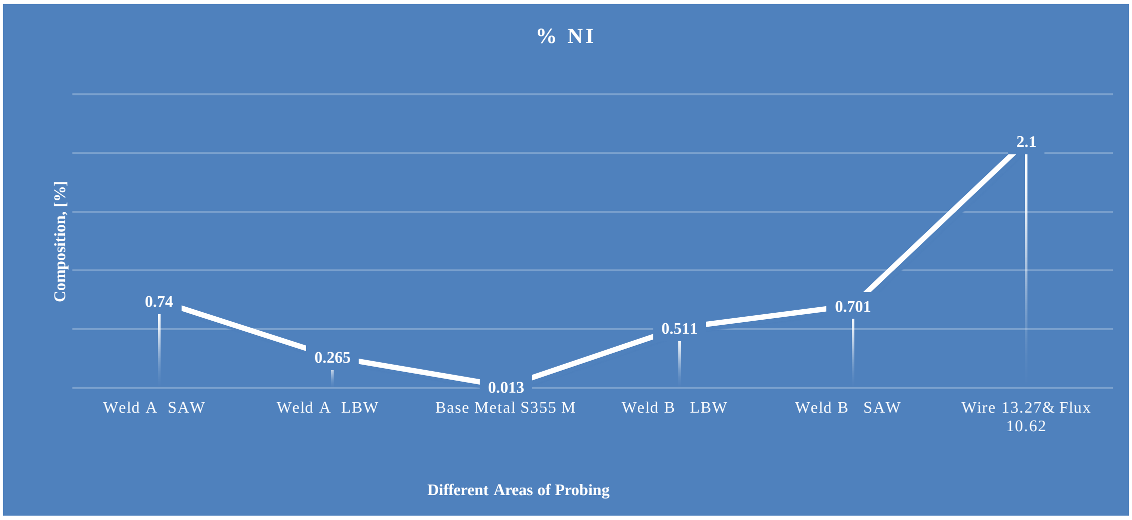

Fig. 6. Chemical Analysis Alternation in Welds A vs. B

Ni element with a composition of 2.1%, is the main alloying element form the weld metal created by ESAB flux 10.62 and wire electrode 13.27. In Fig. *6*, it is seen that the amount of Ni in SAW dominated area of weld A and B is approximately 0.7%. The same for LBW dominated area is different. Weld A has 0.265% Ni while weld B showed 0.511%, meaning that the wire and flux combination has had much more influence in LBW dominated area of weld B.

4.2. Hardness Test

Vickers Hardness test method with a normal-loaded range, HV 5 (49 N test force), was implemented to understand how the base metal, weld metal and HAZ in different areas in the transverse cross section respond to the penetration of the diamond pyramid. Five areas of interest, R1 and R5 in SAW dominated areas located in 5 mm in depth, R2 and R4 in LBW dominated areas located in 15 mm in depth from each side of the work piece and R3 in the middle of that, in addition to a through thickness one, R6, were subject to hardness measurement to understand different behaviors of these areas of interest against the plastic deformation caused by the indenter, as plotted in Fig. 7.

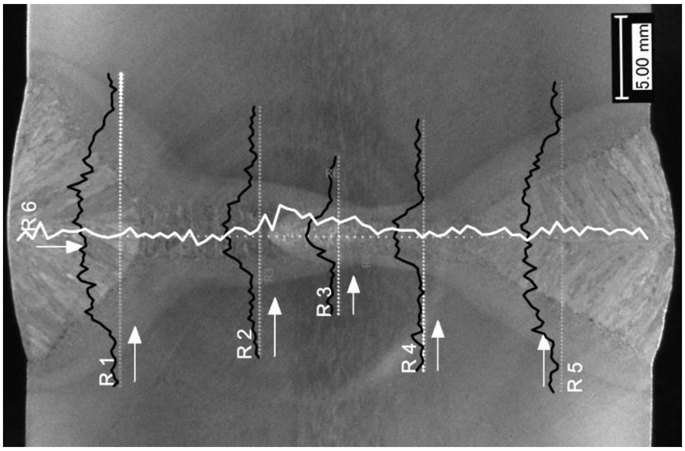

Fig. 7. R1, R2, R3, R4, R5 and R6 curves represent hardness measurements results in the areas of interest

The base metal hardness was measured 177 HV in average. R1, R2, R4 and R5 (black colored in Fig. 7) showed roughly the same hardness range of 160 to 254 HV averaged in 198 HV and in HAZ these values were 167 to 240 HV and 200 HV, respectively. Just in the middle of the thickness, R3, the LBW overlapped area between welds A and B, hardness value came up with the average of 200 HV in the range of 172 to 254 HV, and the highest value of hardness in this area of interest is just centered in the cross section.

R6 (white colored in Fig. 7), the through thickness hardness measurement, covers all the two weld seams in the cross section, ranged from 217 to 250 HV with an average of 230 HV. The maximum hardness value in this area and all the other areas of interest was found to be in HAZ of LBW dominated area of weld B by 279 HV. This high value of the harness can be an indicator of brittle microstructures, leading to low toughness properties. Refer to NACE MR0175 General Principles for selection of cracking-resistant materials (15156-1, 2001) and other manufacturing and construction standards/codes such as API 5L, Specification for Line Pipe ((5L), 2008) maximum hardness in root weld and its HAZ shall be less than or equal to 250 HV.

4.3. Further Decrease in Process Distance (X_{PD})

Setting the angle between laser beam and work piece surface equal to 14° brings the chance to have less process distances. This would help to see how the weld seam is altered when smaller process distances are practiced. To do this important, weld F was deposited with a decreased process distance from 19 to 15 mm.

SAW welding parameters were 35 volt and 2.1 m/min wire feeding rate. The laser power was 16 kW. Welding travel speed was set as 0.6 m/min.

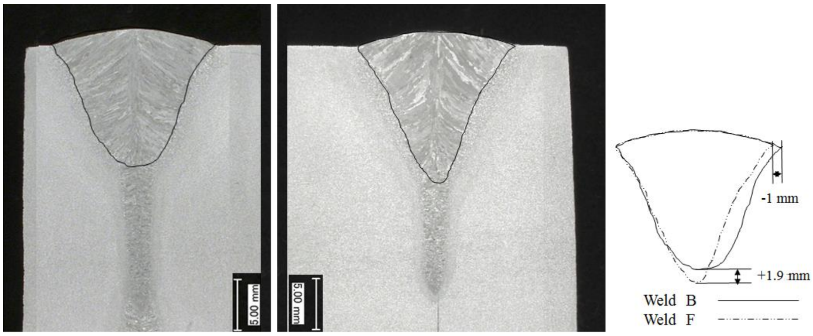

Fig. 8. (Left) Weld B with process distances = 19 mm; (Right) Weld F with process distances = 15 mm

Geometrical measurements from transverse cross sections gotten from welds B and F made data in Table 3. A decline from 19 to 15 mm in process distance shortened the width in cab reinforcement of SAW dominated area by 1 mm while it enlarged the depth of penetration about 2 mm to make an increase in the total depth of penetration by 1.1 mm. The SAW dominated got smaller by about 9 mm^2, See Figure 8.

Table 3. Geometrical measurements of weld seams in cross section

Weld No.	SAW Width, [mm]	SAW Depth of Penetration, [mm]	LBW Depth of Penetration, [mm]	Total Depth of Penetration, [mm]	Total Depth of Penetration, [mm^2]
B	16	12.6	13.2	25.8	123.9
F	15	14.5	12.4	26.9	115.2

In order to show how different heat sources have influence in the geometrical shape of the weld seams in the transverse cross sections, weld C - single SAW, weld D - the LB-SAW hybrid, and weld E - single LBW processes were deposited in the same material thickness and specification, see Fig. . Thanks to the synergic heating effect of the hybrid process in weld D both SAW and LBW dominated areas were enlarged in depth of penetration by 6.5 and 1.5 mm respectively when compared to welds C and E.

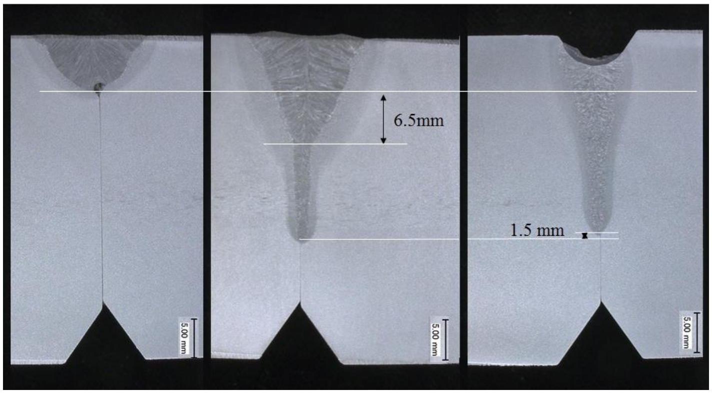

Fig. 9. (Left) Weld C-Single SAW; (Middle) weld D- LB-SAW Hybrid; and (Right) Weld E-Single LBW

In respect to geometrical shape in longitudinal cross section, the behavior of the LB-SAW Hybrid process was investigated in weld F. This is important in the weld design, here as double sided – single pass, since the two weld seams should make secure a sufficient overlap with their depths of penetration so that their fluctuations along with the weld seams do not cause any lack of penetration.

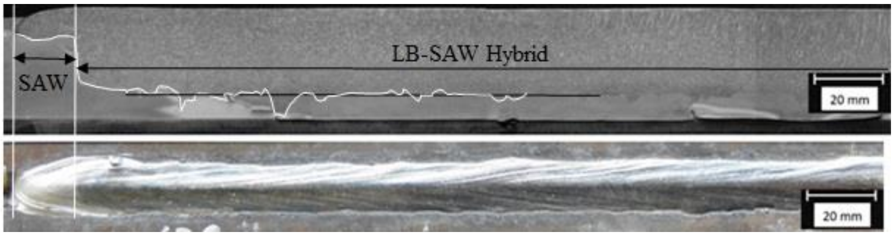

Fig. 10. (Up) Fluctuations in depth of penetration of longitudinal cross section weld F; (Down) Weld seam surface

Looking at Fig. , in the first 18 mm of the weld F, there is no influence of laser beam, but SAW. Considering the process distance of 15 mm, it can be resulted that the laser beam helps the hybrid process after 3 mm from start up the process in actual fact. After this location, hybrid process deposits the weld metal with some fluctuations along with the weld seam length, ranged from 22 to 28 mm. Such fluctuations may cause lack of penetration.

5. Conclusion and Outlook

Using LB-SAW Hybrid welding process material S355 M, thickness 40 mm, with a double sided V groove-single pass weld design, was welded. To study the influence of laser optics and the submerged arc welding torch angel alternation and resulted process distances in geometry, chemistry and hardness concerns, different weld seam were deposited.

Having a reduced process distance from 24 to 19 mm, the width of SAW dominated area got smaller by 3.4 mm while its depth of penetration became 5 mm larger to create an increase in the total depth of penetration from 22.5 to 25.8 mm (weld B). The width of LBW dominated area experienced a decrease from 4.6 to 2.9 mm. The alternation in depth of penetration along with the weld seam length was measured 4 mm. Chemical analysis showed that with such a change in process distance, the weld seam got hybrid with the main alloying element indication, Ni content in weld B raised to 0.511%, about two times more than weld A. Hardness values ranged from 160 to 254 HV in different areas of interest, except for HAZ in laser beam dominated area of weld B with 279 HV, were found to be in compliance with different manufacturing and construction norms.

A hybrid welding set up creating more stable conditions to minimize the alternations in depth of penetration and more influence in the chemical composition of weld metal in laser beam dominated area are planned to practice. Further investigations in mechanical properties and improving them in the weld seams are also necessary to understand how the joint will withstand against different loading conditions.

Acknowledgements

The IGF-Project „Erprobung des Laserstrahl-Unterpulver-Hybridschweißverfahrens für die industrielle Anwendung im Bereich großer Blechdicken (LUPuS)", IGF-Projekt Nr. 19.039 N, of the Research Association Forschungsvereinigung Stahlanwendung e.V. FOSTA, Sohnstraße 65, 40237 Düsseldorf has been funded by the AiF within the programme for sponsorship by Industrial Joint Research (IGF) of the German Federal Ministry of Economic Affairs and Energy based on an enactment of the German Parliament.

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