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Influence of the Laser and its Scan Width in the LDNA Surfacing Process

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Abstract

The novel laser-assisted double-wire non-transferred arc (LDNA) surfacing process that melts two consumable wires with an arc between them and uses a laser to guide the process has shown very promising results. Investigations show that it is possible to create single seams with a complete bond and low dilution at a deposition rate of 7.5 kg/h. In case of multiple seams, joint defects might be formed between the seams due to unfavourable seam geometry. In this paper, results on the optimization of this geometry with an adapted laser scan width are presented. An average connection angle of 93 degrees has been achieved on the side of the weld, where additional seams are placed. It is expected that with these results multiple seams can be welded without producing joint defects, thus leading to an intact layer.

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Keywords: surfacing; cladding; process combination; laser; electric arc

1. Introduction

In industry, many tools are subject to constant wear which leads to large maintenance and replacement costs. To improve the lifetime of the tools, hardfacing is used to protect or repair the parts most prone to damage. This technique is used for example in the mining and automotive sectors.

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There are multiple methods to apply a coating to large surfaces such as Gas Metal Arc (GMA) welding, Plasma Transferred Arc (PTA) weld cladding, Submerged Arc Welding (SAW) and laser cladding. GMA welding typically has deposition rates between 0.9 and 5 kg/h with a dilution of 10-50% (Davis, 1993; Fahrenwaldt & Schuler, 2006; Nouri & Malek, 2007; Shahi & Pandey, 2007). Using a specialized tandem weld cladding method, rates as high as 20 kg/h and dilutions lower than 11% can be achieved (Cramer, 2001). PTA weld cladding constricts the plasma arc with a shielding gas and can achieve dilutions lower than 1% with a deposition rate of 2 kg/h, but the typical process has a dilution of 5-20% and a deposition rate of 7 kg/h (Davis, 1993; Deuis, Yellupb, & Subramanian, 1998; Kim, Yoon, & Lee, 2002). Typically the SAW process has deposition rates of 5-9 kg/h and dilutions ranging from 30-60% (Davis, 1993). More recent investigations have shown that the process is capable of much lower dilutions. At a deposition rate of 8.58 kg/h, a dilution of 12.8% has been reached (Tarng, Juang, & Chang, 2002). With multiple wires, the SAW process raises the deposition rate to up to 27 kg/h with a dilution of 15-25% (Davis, 1993). Laser cladding can have a deposition rate of up to 9 kg/h with a dilution of 1-10%, but requires a 10 kW laser to achieve these results. By combining the process with an inductor, up to 16 kg/h can be reached using 8 kW laser and 12 kW induction power (Brückner, Nowotny, & Leyens, 2012).

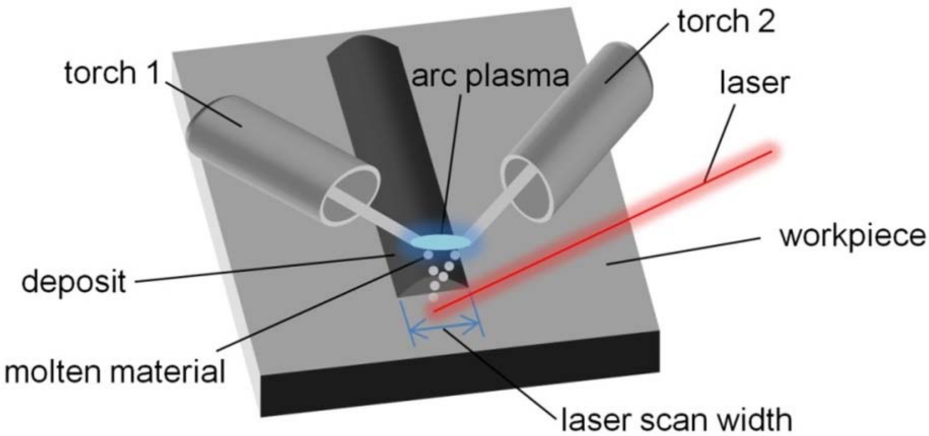

Fig. 1. Double-wire Non-transferred Arc surfacing process.

The Laser-assisted Double-wire Non-transferred Arc (LDNA) surfacing process (Fig. 1) has been developed to provide a surfacing technology that combines the low dilution of laser processes with the high deposition rates and low costs of electrical arc processes (Barroi, 2013). In this welding technique, an electric arc is established between two consumable electrodes which provide the deposition material. Therefore, most of the arc energy is used for melting the wires, potentially providing extremely high amounts (>20 kg/h) of surfacing material to the process. Furthermore, the arc is not transferred to the workpiece. By this measure, the heat input to the workpiece is decreased which also reduces warpage. The heat input from the melt is so low, that the substrate is not melted on the edges of a seam and is therefore not welded to the deposited material. To achieve a sound weld, additional heat is needed in these regions. Using a laser which is deflected by an oscillating mirror (scanner), the desired heat distribution can be added to the process region. The laser radiation, which is focused in the process zone and is oscillating perpendicular to the welding direction, does not only contribute energy to the process, but also influences the geometry of the seam. This is needed to flatten the sides of the seams to prevent joint defects from indents, as shown in Fig. 2.

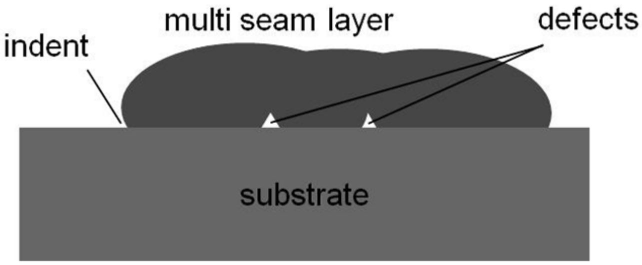

Fig. 2. Joint defects between seams due to unfavourable shape.

2. Experimental

The setup for the LDNA surfacing process includes a laser head with the optics that are required to focus the laser, a scanner to deflect the laser radiation and two GMA torches which are positioned by the torch holder. The torch holder also acts as a gas nozzle for the shielding gas supplied by the torches. These torches lead the wires. Wire 1 is positively charged, and wire 2 is connected to ground. Therefore, the arc is established between the wires and not transferred to the workpiece. The wire angles are different in order to compensate the asymmetrical process, which is governed by physical effects like arc pressure and the magnetic field generated by the welding current.

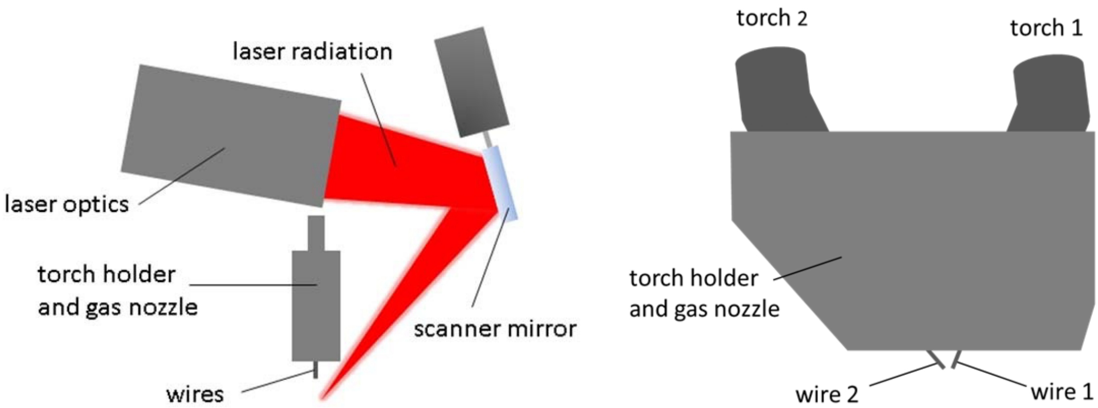

Fig. 3. Experimental setup.

In order to investigate the influence of the laser-induced heating on the process, cross-sections of weld seams created with different laser scanning widths have been compared to each other and to cross-sections of weld seams created by the arc only. A mirror was used to vary the scan width between 10.5 mm and 17.3 mm at six evenly spaced intervals. The frequency of the sinusoidally rotating mirror was set to 10 Hz. This setting results from the used welding speed and allows the focal spot to have a slight overlap in welding direction, when returning after each period. The wires used for this experiment had a 1.2 mm diameter and consisted of 1.4430 stainless steel. 20 mm thick S355 mild steel plates were used as substrates. The surfaces were milled to a RMS roughness of 0.45 µm measured perpendicular to the welding direction. Prior to the tests, they were cleaned with isopropyl. To shield the process from atmosphere, a gas mixture of 82% Argon and 18% CO_2 was used. The laser heating was implemented by the use of a Trumpf disk laser emitting at 1030 nm. Further process parameters are listed in Table 1.

Table 1. Process parameters.

Parameter	Value	Unit
Laser power	1000	W
Focal length of focusing optic	300	mm
Shielding gas flow rate	20	l/min
Wire speed (torch 1)	7.6	m/min
Wire speed (torch 2)	6.4	m/min
Welding speed	300	mm/min

For each laser scan width, four tests were conducted. The first 4 cm of each sample were discarded, as the weld takes a few seconds to stabilize. Four evenly spaced cross-sections were cut from the remaining length of the sample with the last cross-section approximately 4 cm from the end. By this means, 16 measurements were taken for each set of parameters. All data taken from the cross-section are described in Fig. 4. The connection angle measures the angle at which the seam and work piece meet. It was only taken on the left side, since additional seams are added only on this side. The weld width measures the entire connected length between the substrate and the seam, while the seam height and width give the dimensions of the seam itself. All cross-sections are facing in welding direction. When discussing the seam, the reference direction will always be the same as the cross-sections.

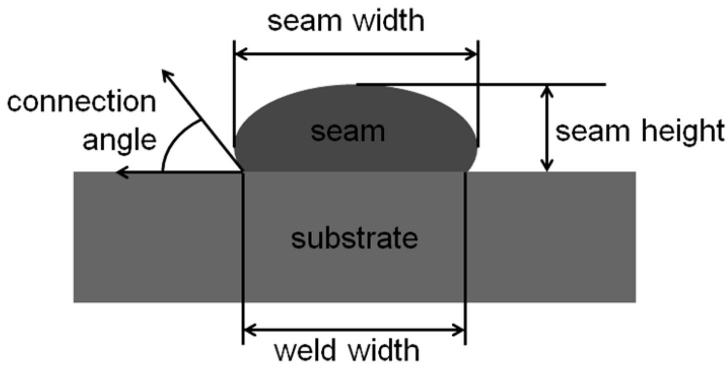

Fig. 4. Measurements.

3. Results and Discussion

To present the results of this investigation, four cross-sections have been chosen that describe the findings adequately. Fig. 5a) shows a cross-section of a seam that was welded only by the arc process without the laser.

There are small connection angles and deep indents on the sides of the seam that would cause a large joint defect, if a second seam was added on either side in order to form a layer. The space of this indent could only be filled by remelting the above lying material, using high amounts of energy. This would lead to unfavourable high heat input resulting in high thermal stress and dilution.

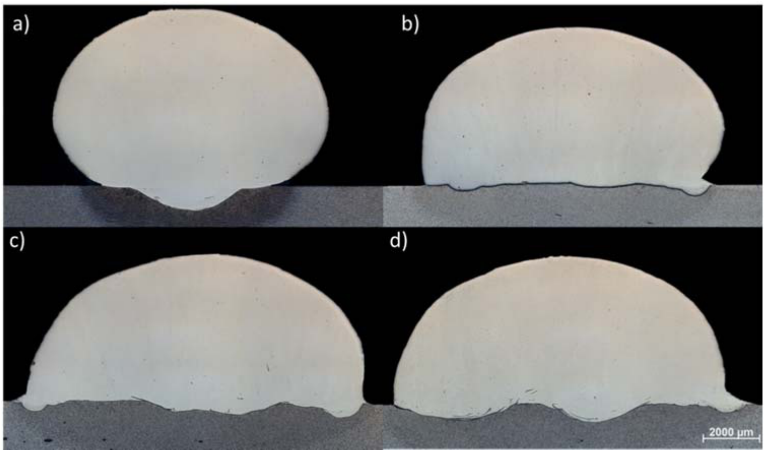

Fig. 5. Cross-sections of samples with varying laser scan widths. a) no laser; b) 10.5 mm; c) 13.2 mm; d) 17.3 mm.

When a laser is used, the seam changes greatly (Fig. 5b-d)). Instead of a centered penetration, the weld width increases, and the penetration is lower and spread out. The indents on the weld sides are reduced or completely eliminated. Several different reasons for this behavior are possible. The energy added by the laser heats the melt, allowing the material to stay molten for a longer period of time. In addition, the increase in temperature of the melt lowers its viscosity (Echendu & Anusionwu, 2011). When observed with a high-speed IR camera, an interesting behaviour can be seen. The melt seems to be pushed to the sides by the laser, widening the seam (Fig. 6). This effect might be caused by pressure from laser-induced sublimation of the melt.

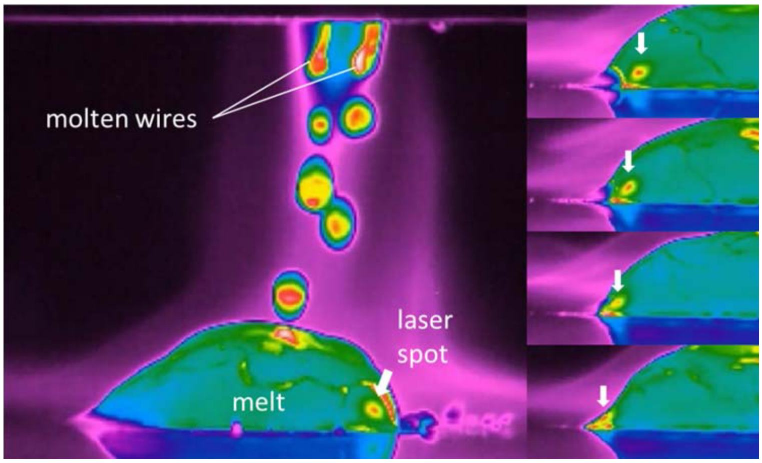

Fig. 6. IR cam process picture showing the laser-induced melt movement, the white arrow points at the laser spot.

The laser-induced melt movement can be utilized in order to form more uniform seam geometries. This only works within a certain limit. When the laser scan width is extended beyond this limit, the width of the seam becomes irregular. Fig. 7a) shows how the laser is used to extend the seam width, which is favourable due to its flattened geometry. The first four data points imply a linear relationship between weld width and scan width within this interval. It is not possible to extend this behaviour further on, as can be seen from the last three data points. These points also show a significant increase of the standard deviation. This means that the geometrical stability of the weld decreases, which would lead to weld defects when welding a layer. Another interesting point in this graph is the low standard deviation at 13.2 mm, indicating high process stability.

Looking at the contact angles in Fig. 7b), it can be seen that at 13.2 mm scan width the greatest angle and the lowest standard deviation of the angles are reached. The average value is 93°, which means that there is no indent in the side of the seam. But when taking the standard deviation into account, indents may occur sporadically along the seam. Therefore, a further increase of this angle is desirable. Fig. 7c) shows that an increase in scan width also increases the seam width with a limit at about 11.9 mm. Therefore, an increase further than 15.9 mm has no significant effect. With an increasing scan width, the standard deviation rises too, indicating that the process is more stable at smaller scan widths. Fig. 7d) shows the decrease of the seam height with increasing scan width. This behavior was expected, since with the increasing scan width the seam width also increases. Therefore, the volume of the seam is flattened. Taking all these results into account, a scan width of 13.2 mm is the best value for the used parameters.

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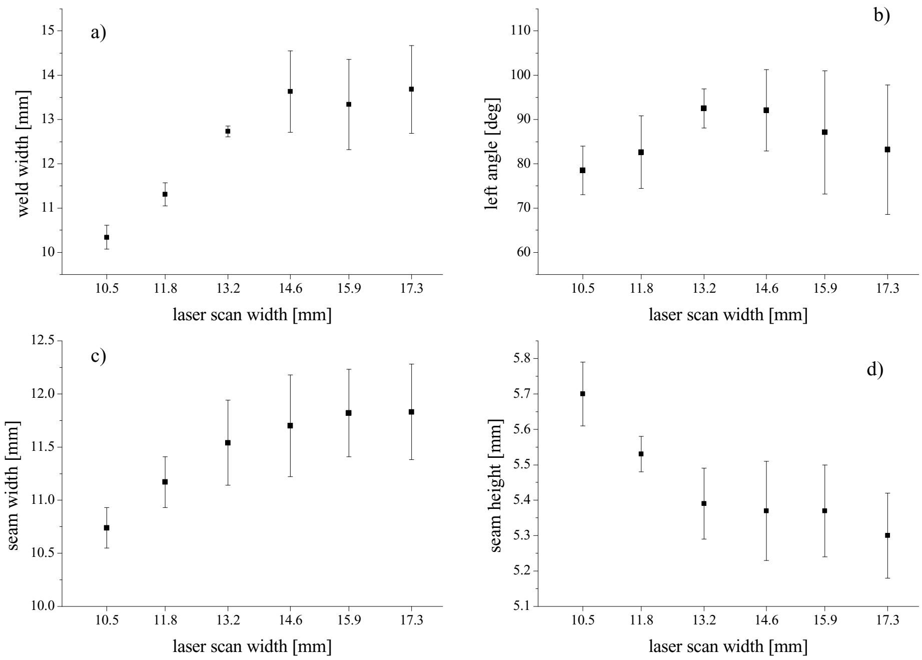

Fig. 7. Influence of the laser scan width on a) weld width b) left angle c) seam width d) seam height. The bars show the standard deviation.

4. Summary and Outlook

The study shows that the laser has positive influence on the seam and weld geometry. At 13.2 mm laser scan width, the best results are obtained for the used parameters. Although the weld width can be further extended, it would lower the uniformity of the weld geometry. Regarding the contact angle, a better value has not yet been obtained and other parameters like welding speed or wire alignment need to be investigated to improve it. Seam width and seam height do not change a lot beyond this value. A further flattening of the seam geometry is desirable, but it is expected that a layer of multiple seams can be welded without joint defects.

The laser-induced melt movement should be investigated in further studies to define its possibilities and limitations. Scan frequency, laser power as well as the surface roughness can be of great influence.

Acknowledgement

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