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Influence of laser spot oscillation parameters on the seam geometry and dilution in the LDNA process

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Abstract

The “Laser-assisted double wire with non-transferred arc surfacing process (LDNA)” is characterized by an electric arc burning between the filling wires. The molten filler material is fed to the substrate surface by gravity and is shaped by a laser beam. In this work, the influence of laser parameters on seam geometry and dilution is investigated. The investigations include a linear and convex pendulum form, a focal length of 300 mm and 400 mm, an oscillation frequency of 10 Hz and a disc laser using a wavelength of 1,030 nm with a power of 1,000 W and 1,400 W. Two 316L filling wires with 1.2 mm and an AISI1024 substrate with 20 mm are used. The change in the dilution and the welding geometry is determined.

Keywords: LDNA; Oscillation; Pendulum form; Additive Manufacturing; Laser spot

1. Introduction

Cladding by Gas Metal Arc Welding (GMAW) is a conventional surfacing process with high reliability, high cost-efficiency and the ability to weld in each welding position [1]. A characteristic of this process is an arc burning between the feeding wire and the working piece. This results in high thermal input and a comparably high distortion. There are approaches to reduce these in processes like the Cold Metal Transfer welding process (CMT) [2]. Another approach to minimize the thermal input of a GMAW surfacing process is the “Laser-assisted double wire with non-transferred arc surfacing process (LDNA)”, a cladding process characterized by two physical principles and spatial separation of the arc and laser beam [1]. The LDNA process is based on two principles. In the first one, an arc ignites between two converging wire materials. The resulting metal droplets fall onto the metal plate in the direction of gravity. In the second, an oscillating laser beam interacts with the molten material and the substrate, improving the seam geometry in width and contact angle by introducing a thermal gradient into the processing zone and widening the melt pool. Consequentially, a low degree of dilution of less than 5 % along the transversal direction at deposition rates of up to 8 kg/h is achieved in comparison to approx. 5 kg/h with a GMAW process. This work investigates the effects of a variation of the laser beam spot size as well as different oscillation patterns with the goal to further lower the dilution and improve the seam quality. The quality is mainly characterized by a sound interconnection as well as a low degree of dilution.

Afterward, investigations are performed for the analysis of the influence of the oscillation parameters and laser spot diameter on the seam geometry and dilution.

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2. State of the art

The main thermal energy input of the LDNA process results from the arc ignition with an energy distribution of approx. 83 %. A further thermal input on the melt pool is necessary for a complete interconnection, otherwise, a deeper fusion penetration at one point and the formation of wormholes in the edge areas are present [3-5].

By scanning along the melt pool at the substrate surface with an oscillating laser beam in the transversal direction, additional thermal energy is provided into the process locally. Thus, a homogeneous temperature profile is created, resulting in a complete melting of the surface and an improvement of the interconnection. The fusion is given over the entire transversal direction and a higher contact angle is detectable. Tube pores no longer occur and the weld becomes flatter and wider [4]. By adjusting the oscillation amplitude, the fusion penetration and the weld geometry are influenced.

Experiments were conducted about the influence of the laser beam position on the seam geometry in the LDNA process. When the laser beam is 1.5 mm in front of the melt pool, the seam has steep flanks. When the laser beam is directed into the melt pool, a smaller irregular seam beginning is observed. [6]

Tyralla performed experiments with Laser Hot Wire Cladding and analyzed the influence of the oscillation form on the seam geometry and dilution [7]. Without the oscillation, the intensity is gathered in the center which leads to a high penetration depth of about 4 mm and a dilution of 87 %. By applying a sinusoidal oscillation, the penetration depth and dilution decrease significantly to 1 mm and 32 %, respectively. A homogeneous intensity distribution can be achieved by a triangle oscillation. In combination with a higher spot diameter of 1 mm instead of 200 µm, the dilution diminishes to 3.5 %.

Mann et al. analyzed the influence of the oscillation frequency and focal diameter on the melt pool shaping [8]. With a rising frequency, the melt pool width and melt pool length increase. Meanwhile, a higher focal diameter results in a larger melt pool width and length.

Ivanov ran numeric simulations of the influence of beam oscillation on melt pool shaping for laser metal deposition. Therefore, lateral and circular oscillations were analyzed. It was observed that a circular oscillation leads to a lower penetration depth caused by a lower peak of the heat flux. For both oscillation forms, the seam width increases and the seam height decreases with a higher oscillation amplitude. [9]

The idea of this work is to reduce the dilution and increase the seam width by changing the linear oscillation form to a convex one, as it has been done for the Laser Hot Wire Cladding.

3. Materials and methods

3.1. Experimental setup

A schematic drawing of the experimental setup for the LDNA-process is shown in Fig. 1. Two feeding wires are supplied by a welding source of *Merkle* with its characteristics shown in [4]. The laser beam source is a *Trumpf TruDisk 16002* laser with an emitting wavelength of 1,030 nm. A 2D-galvanometer scanner is used for the laser beam control along the transversal direction.

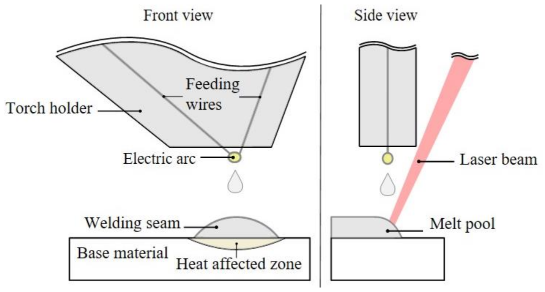

Fig. 1. Principle of the LDNA process with a laser beam moved by a 2-axis-scanner.

3.2. Materials

For the investigations, mild steel AISI 1024 is used as substrate and stainless steel 316L as feeding wires. Sandblasted substrates ensure a homogenous surface and homogenous brightness for a constant absorption of the laser beam. When the distortion is too high, the working distance decreases and the arc process is not be stable. Therefore, the thickness of the working piece is set to 20 mm and the deposition rate is set to 8 kg/h with a current of 170 A and a voltage of 28 V.

Substrates with dimensions 230 x 150 x 20 mm^3 and feeding wires with a diameter of 1.2 mm are utilized. Ar + 18 % CO$_2$ is used as shielding gas to prevent oxidation and guarantee a stabilized arc burning without spatters. Therefore, a flow rate of 28 l/h is used.

3.3. Methods

The experiments are executed with a variation of following parameters:

- Oscillation form: linear and convex,
- Oscillation amplitude: 12.7 mm, 13.2 mm and 13.7 mm,
- Distance of adjacent seams: 7 mm and 7.5 mm,
- Focal length of focusing lens: 300 mm and 400 mm and
- Laser power of 1,000 W at a focal length of 300 mm and 1,400 W at a focal length of 400 mm.

To investigate the influence of the single parameters on the target variables, the seam geometry and dilution are examined. Three repetitions per parameter set are conducted.

At a focal length of 300 mm, the laser spot diameter is about 1.8 mm and while it is set to 4 mm at a focal length of 400 mm. A linear oscillation means a horizontal movement along the transversal direction (cf. Fig. 2). A convex oscillation form is a parabolic movement with a curvature of 0.5 mm.

The working distance, defined as the vertical distance between the welding torch holder and the substrate, is set to 10 mm. An angle between the torch holder and laser beam of 30 ° is set, observed by Barroi for optimal influence for shaping the melt pool for a homogenous seam geometry and a higher connection angle [1]. The laser beam is moved sinusoidally by a 2-axis-scanner along the seam transversal direction. The working piece is accelerated to 600 mm/min before the arc

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ignition. After the ignition, two adjacent seams of 100 mm length are deposited. The process environment has a temperature of 18 °C and a humidity of 68 %.

3.4. Analysis

The welding seam is discarded 30 mm (cf. Fig. 3, position A), 50 mm (position B) and 70 mm (position C) after the seam beginning. At these positions, the analysis of the dilution and seam geometry is executed with cross-sections (cf. Fig. 4). The laser scanning microscope *Keyence VK-X1100* is used to analyze the resulting topology of the welding seams.

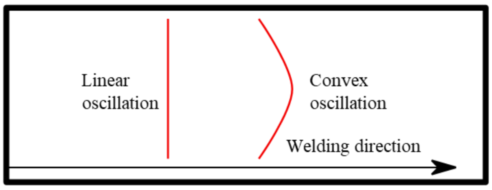

Fig. 2. Linear and convex oscillation form of the laser beam along the transversal direction at a top view of the substrate.

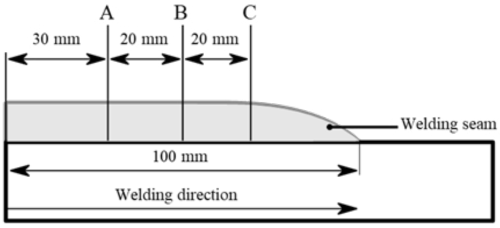

Fig. 3. Position of cross-sections for analysis of dilution and seam geometry.

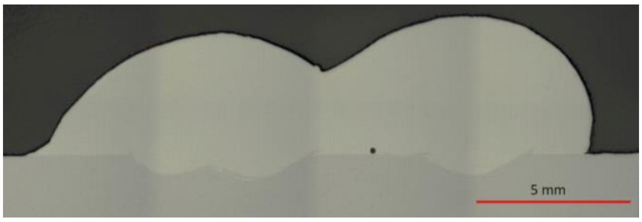

Fig. 4. Cross-section of two adjacent seams with 7 mm distance, 12.7 mm oscillation amplitude, convex oscillation form and 300 mm focal length.

4. Results

4.1. Seam geometry

Investigations with an oscillation frequency of 10 Hz showed welding seams with a constant geometry. With an increase of the oscillation frequency above 20 Hz, the effect of weld seam shaping is not observed. Thus, the frequencies of 20 Hz and 30 Hz are not practicable.

The influence of the oscillation amplitude and oscillation form on the seam geometry is displayed in Fig. 5 and Fig. 6 with a focal length of 300 mm, starting with the linear oscillation of the laser beam and a distance of 7 mm between adjacent seams. With a higher oscillation amplitude the seam width increases from 17.9 mm to 19.5 mm, resulting in a decrease in the height from 4.5 mm to 4.4 mm.

With the use of a convex oscillation amplitude, the seam geometry is modified. The seam width increases from 17.9 mm to 18.7 mm and the maximum seam height slightly rises from 4.5 mm to 4.6 mm, with an oscillation amplitude of 12.7 mm. With a higher oscillation amplitude of 13.7 mm, the seam width increases to 19.9 mm. The higher width is caused by the movement of the melt pool which is guided by the convex oscillation of the laser beam. In comparison to a linear oscillation form, the curvature leads to a wider melt pool at the edges.

By changing the distance of the adjacent seams from 7 mm to 7.5 mm, the seam width increases from 17.9 mm to 18.8 mm with the linear oscillation form and from 18.7 mm to 19 mm with the convex form.

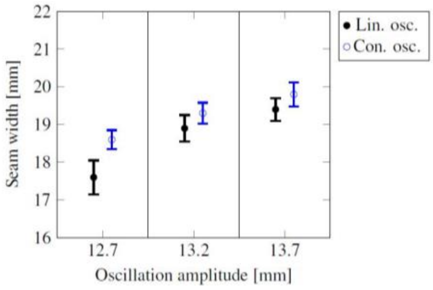

Fig. 5. Seam width of adjacent seams with 7 mm distance depending on oscillation amplitude and oscillation form with 300 mm focal length.

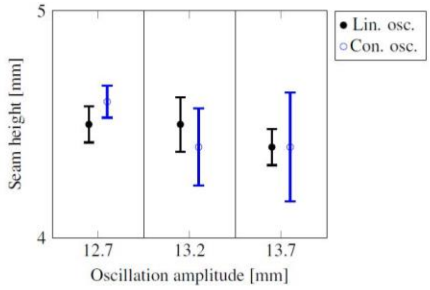

Fig. 6. Seam height of adjacent seams with 7 mm distance depending on oscillation amplitude and oscillation form with 300 mm focal length.

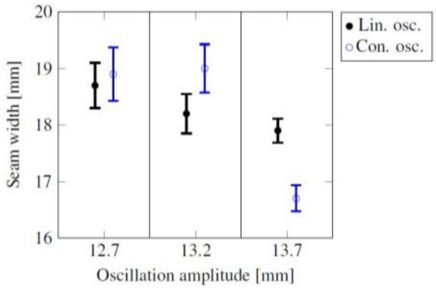

Fig. 7. Seam width of adjacent seams with 7 mm distance depending on oscillation amplitude and oscillation form with 400 mm focal length.

In Fig. 7 and Fig. 8 the results of the focal length of 400 mm are shown. The seam width rises from 17.6 mm to 18.7 mm with an oscillation amplitude of 12.7 mm, decreases to 18.2 mm with an amplitude of 13.2 mm and to 17.9 mm with

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an amplitude of 13.7 mm. In comparison to the results of the focal length of 300 mm, the seam width is only higher with an oscillation amplitude of 12.7 mm caused by the bigger laser spot diameter. Thus, the melt pool is expanded more in the edges where the oscillation movement is changing. With amplitudes of 13.2 mm and 13.7 mm, the laser beam of the second seam has an overlap with the previous seam and does not widen the melt pool in a maximal manner.

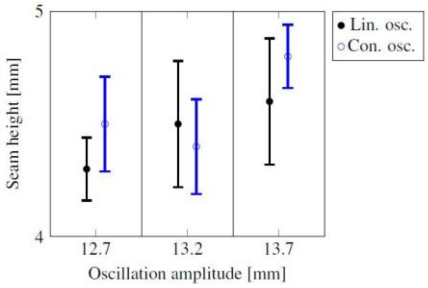

Fig. 8. Seam height of adjacent seams with 7 mm distance depending on oscillation amplitude and oscillation form with 400 mm focal length.

4.2. Dilution

In Fig. 9 the dilution for a variation of the oscillation amplitude and oscillation form is displayed. It was observed that the oscillation form has no significant impact on the dilution. With a linear oscillation form the dilution is about 7 % to 8.1 % in comparison to a convex oscillation form with a dilution between 7.9 % and 8.3 %, both with a distance of 7 mm of adjacent seams and a focal length of 300 mm. Thus, a significant influence of the oscillation form on the dilution is not determined.

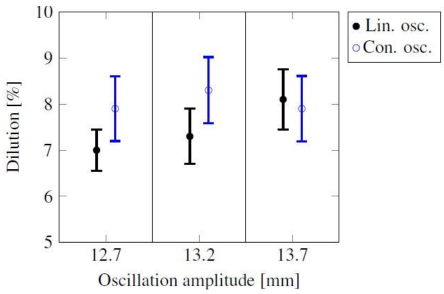

Fig. 9. Dilution of adjacent seams with 7 mm distance dependent on oscillation amplitude and oscillation form with 300 mm focal length.

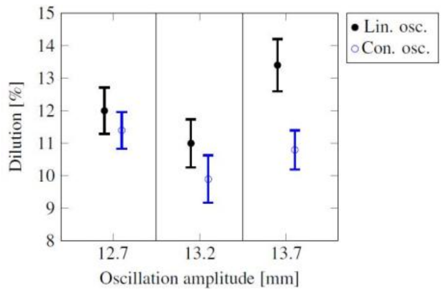

Fig. 10. Dilution of adjacent seams with 7 mm distance dependent on oscillation amplitude and oscillation form with 400 mm focal length.

By changing the distance of adjacent seams from 7 mm to 7.5 mm, the dilution increases from 7 % up to 12 % for the linear oscillation and from 7.9 % up to 10.3 % for the convex oscillation. With a higher distance, the heat input into the substrate and consequently the dilution rise.

Comparing Fig. 9 with Fig. 10, an influence of the focal length can be seen. Thus, a direct connection between the laser spot intensity and dilution can be derived. Even though the 300 mm focal length has a smaller focus spot diameter, hence higher intensity, the dilution is reduced. This behavior can be explained by the influence of the laser beam on the melt pool. With higher intensity, the melt flows further in the direction of welding. Therefore, the molten wire droplets impact on the melt pool instead of on the substrate surface. Since the droplets are hotter than the melt pool, the substrate is shielded by the pool.

The dilution range is from 9.4 % to 13.4 % for a linear and 9.9 % to 11.4 % for a convex oscillation form. The higher laser output power and the longer focal length result in an increase of the thermal impact on the working piece. By increasing the distance of adjacent seams from 7 mm to 7.5 mm, the dilution is increased up to 11.9 % because of the higher thermal input into the substrate.

5. Conclusion

In this paper, the influence of the laser spot oscillation parameters on the melt pool in the LDNA process is investigated. Therefore, experiments with a linear and a convex oscillation form in combination with a variation of the oscillation amplitude and distance of adjacent seams were executed. It was observed that a higher seam width can be achieved using a convex oscillation form. A significant influence of the oscillation form on the dilution was not determined. Further investigations of the convex oscillation form with higher oscillation amplitudes than 13.7 mm need to be performed to explore the limits of this oscillation form.

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