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Influence of laser power on the shape of single tracks in scanner based laser wire cladding

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Abstract

The shape of the cladding tracks is extremely important for producing layers or structures by adding them sequently. This paper shows the influence of the laser power of a diode laser in the range of 500 to 1000 W on the shapes of single tracks in scanner based laser wire cladding. The scanner was used to oscillate the beam perpendiculary to the welding direction. Stainless steel (ER 318 Si) wire with a 0.6 mm diameter was used as deposition material. Height, width, penetration, molten area and weld seam angles of single tracks were obtained from cross-sections at three different positions of each track. The influence of these different positions on the results depends on the traverse speed. The paper discusses this influence in respect to the heat dissipation in the substrate material.

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Keywords: laser cladding; wire; shape; laser scanner

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1. Introduction

In industry, many tools and parts have a reduced life cycle due to wear. Cladding technologies are commonly used to apply a wear-resistant layer over them. The use of the laser cladding technology is increasing because of advantages such as reduced dilution and thermal deformations when compared to other cladding technologies. The wire feeding option – instead of powder feeding – is also growing in industry because of storage ease, increased health safety and reduced waste of material.

To fit a clad to a specific welding situation it is crucial to be able to determine the shape of the tracks that are used to form the desired deposition geometry. A flat track, for example, is well suited when welding a protective layer.

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When welding on the edge of a work piece or when building up a structure, a higher track with steep sides is more beneficial.

Many different approaches relating process parameters to track geometry are presented in the literature, most of them modeling powder fed processes. Kumar et al. (2012) predict a single track geometry in two dimension based on a detailed finite element model, taking process parameters as input data. Their data was experimentally verified, obtaining low average errors for track height and width. Costa et al. (2003) also predicted track geometry, but with a simpler semi-empirical model based on combined roles of different process parameters. De Oliveira et al. (2005) also performed some experiments relating combined parameters to the main clad dimensions, after calculating the required energy to melt separately substrate and additive material. The combined parameters found differed from each author, which was expected due to the results experimental nature. Paulo Davim et al. (2008) successfully established relations between process parameters and geometry features by multiple regression analysis. Saqib et al. (2014) proved that those relations can also be found running simple statistical methods on experimental data. El Cheikh et al. (2012) modeled the track upper section as a circle and calculated its center and radius based on the process parameters. Pinkerton and Li (2004) modeled not only the upper part, but both sections of the track as detached arc circles. After that, they used mass and energy balance to define the boundaries of the molten pool, obtaining the track geometry. In both papers the models were tested experimentally, obtaining good correlations. The geometry of cladded layers was also investigated. Nenadl et al. (2014) and Ocelík et al. (2014) predicted a layer geometry with a recursive geometrical model based mostly on a single track profile and the overlap between tracks. Their works were experimentally verified, successfully predicting the layer geometry. All those models, however, were based on powder fed systems.

Models relating track geometry and process parameters for wire fed process, however, lack on references in the literature. Syed and Li (2005) researched the effects of wire position, angle and direction on surface finish and geometry stability. In their study, front feeding with the wire tip near the molten pool's leading edge was the optimum setup. Klocke et al. (2012) found a relation of laser power and traverse speed to maintain the track shape constant. Pekkarinen (2015) adjusted the power distribution with a scanner system to influence the track shape. Barroi et al. (2011) used a laser assisted electrical arc process for build up welding and determined the layer height and a method to overcome geometrical problems at the start and end of the tracks. Kim and Peng, (2000) studied the plunging method for laser cladding with wire, being able to stabilize it, obtaining solid bonding and good surface finish. First steps towards geometry modelling for wire based cladding are the topic of this work. One of the most important parameters, the laser power and its influence on the track shape was investigated.

2. Experimental

The experiments were performed using a 2 kW Laserline diode laser emitting at 1025 nm. A 400 µm fiber delivered the radiation, which was shaped with a 100 mm focal length collimator lens and a 400 mm focal length focusing lens. The projected laser spot was moved perpendiculary to the welding direction by an oscillating mirror - a laser scanner. This scanner is controlled by a function generator, which allows to vary its amplitude, frequency and waveform. The deposition material is supplied by a wire-feeding system produced by Dinse, which is able to handle the 0.6 mm diameter wire and monitor the feeding speed. Fixed parameters of this investigation were the argon shielding gas with a flow rate of 6 ln/min, wire type (ER 318 Si), wire feed speed of 0.6 mm/min and the scanner parameters. The scanner was oscillated at a frequency of 50 Hz with a symmetrical ramp function and an amplitude of 1.1 mm peak-to-peak on the workpiece. With a laser spot size of 2.9 mm, the oscillation leads to an elliptical spot with 2.9 mm in direction of the weld and 4 mm perpendicular to this direction. The traverse speed of 2.2 mm/s was chosen due to two reasons: low deviation of the cladding area, which allows a better evaluation of the results and low deviation of the height, which means that the cumulated heat in work piece has a small influence on the results. The latter point will be further discussed in the results section. The tests performed to determine these deviations were done at a constant laser power of 640 W and with seven traverse speeds ranging from 0.83 mm/s to 5.83 mm/s.

The variable parameter in this investigation on the shape of the track was the laser power. It was varied in 7 equally spaced steps from 475 W to 805 W.

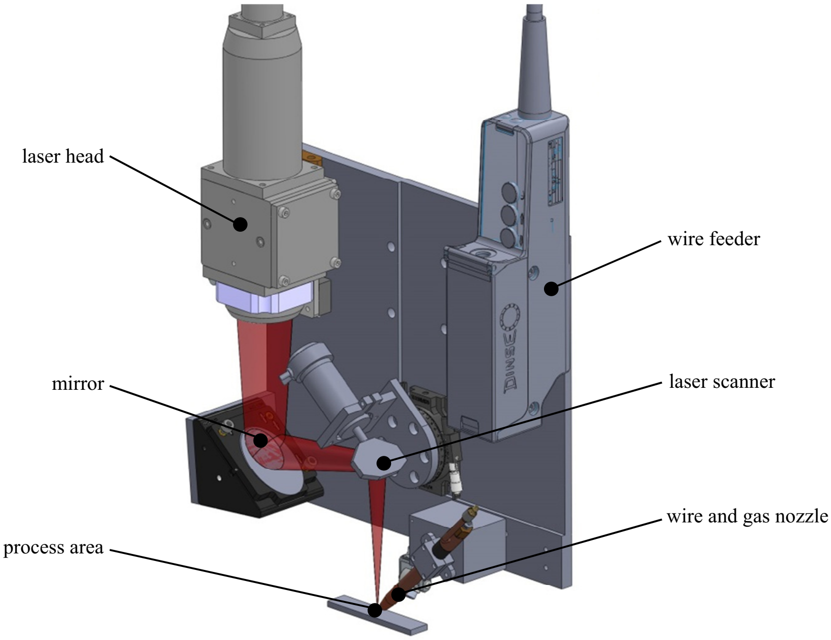

Fig. 1. Experimental setup.

In order to measure the shape of the tracks, cross-sections have been prepared from three sections of each track. The measurements include the hight and the width of the track, the penetration depth into the substrate material and the area of the molten material of the substrate. Also the contact angles of the tracks have been measured. Those are the angles spanning on the inside of the track, measured from the substrate surface to the tangent of the surface of the deposit where it touches the substrate material.

3. Results

The results are structured into two different parts. First, the preliminary tests to determine low deviation parameters are described. Then, the investigations on the influence of the laser power on the shape of the single tracks are discussed.

3.1. Determination of the traverse speed

At low traverse speeds, it was observed that the shape of the track changes along its path. The track becomes lower as shown in figure 2. This behavior is reduced when raising the traverse speed. On the right side of figure 2 the same tracks are shown in respect to the work piece temperature, measured with a pyrometer 10 mm in front of the welding position. For the cladding process, the temperature difference of the work piece surface in the process area to the melting point of the material is important. Since it was not possible to measure the temperature directly in this region, a point on the welding path provided the best approximation for the influence of the temperature. From this measurement, it can be seen that the influence of the heat dissipated into the material decreases with higher traverse speed.

Regarding the deviation of the cladding area for different traverse speeds, a decrease with lower traverse speeds can be seen in figure 3. This means that a compromise had to be found to achieve low deviations for heights and clad area. At the traverse speed of 2.2 mm/s the change of height and the clad are deviation are rather small and were therefor choosen for the further experiments.

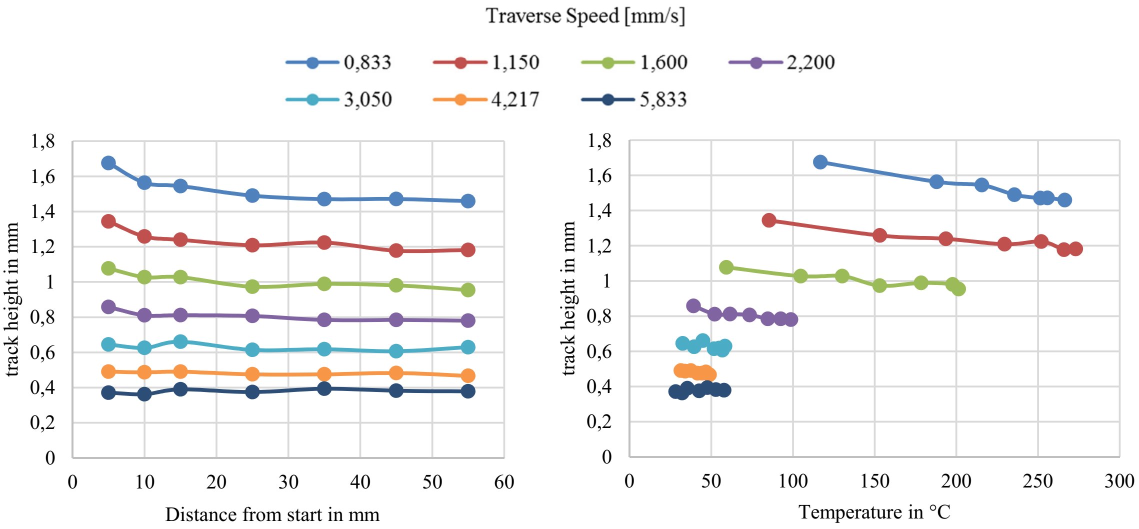

Fig. 2. Height of track at different positions, welded with 640 W laser power left: height of the tracks at different positions welded with different speeds right: height of the tracks at different positions in respect to the work piece temperature.

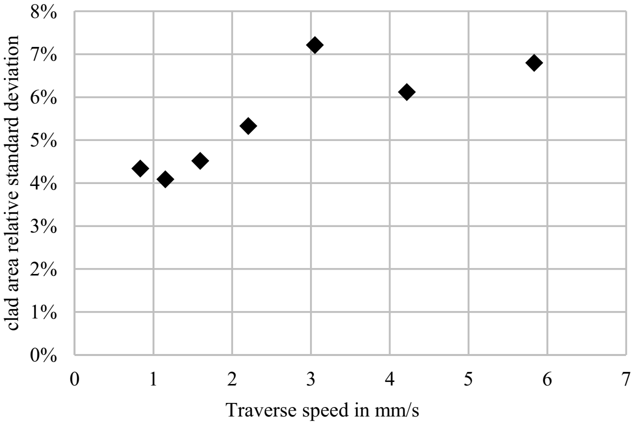

Fig. 3. Decrease of relative deviation of the clad area with slower traverse speeds.

3.2. Influence of laser power on the track shape

The laser power is one of the most important parameters in laser cladding. It is obvious, that it changes the amount of material which is molten by the process. The same behavior is valid for the penetration depth. For both values, there is an offset of about 500 W. This offset is due to the amount of energy needed to meld the supplied deposition material. From that point on, linear relations for the tested parameter range were observed (figure 4).

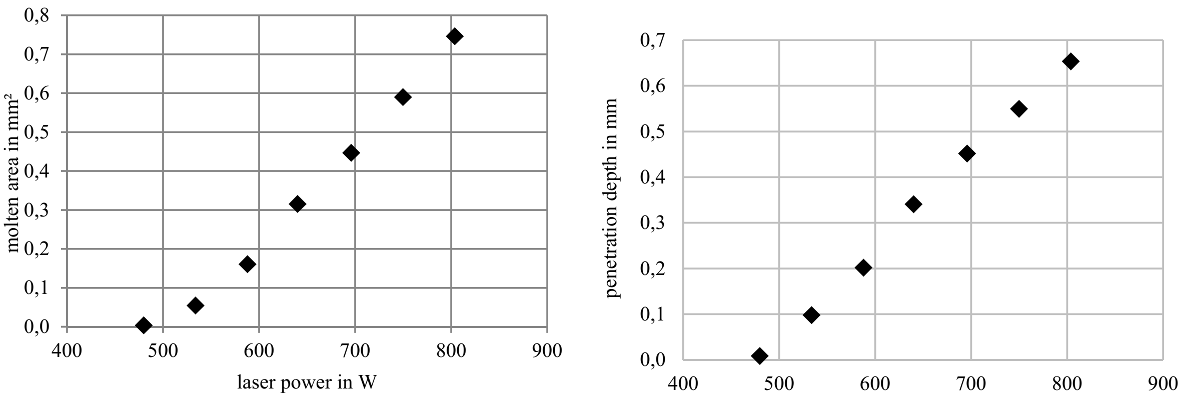

Fig. 4. left: Molten area of the subtrate material in respect to the laser power right: Penetration depth in the substrate material in respect to the laser power.

The primary issue of this investigation was the shape of the deposit and how it can be influenced by the laser power. A raise of laser power led to hoter melt which then flew further to the sides. Therefore, the track became flater and wider as can be seen in figure 5. An asymptotic fitting on the height values with a correlation factor of 0.977 showed that a further raise in laser power would reduce the height to a minimum of 0.64 mm. The same fitting applied on the width values had a correlation factor of 0.997 and showed, that a raise in laser power would not raise the width to more than 2.7 mm.

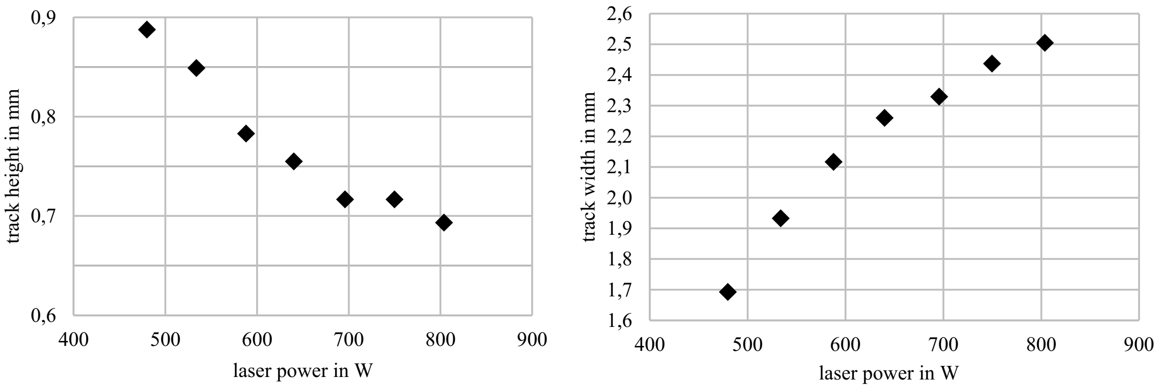

Fig. 5. left: Height of a single track in respect to the laser power right: Width of a single track in respect to the laser power.

The contact angles of the deposite agree with the flatness of the track. In figure 6, the contact angles decrease with higher laser power, reaching a minimum of about 50°. Also, some deviation from steadily asymptotic behavior can be seen. The main reason for this is the measurement procedure. Since the shape of the deposit is not an ideal geometrical form, placing a tangent for the angle measurement cannot be done precisely.

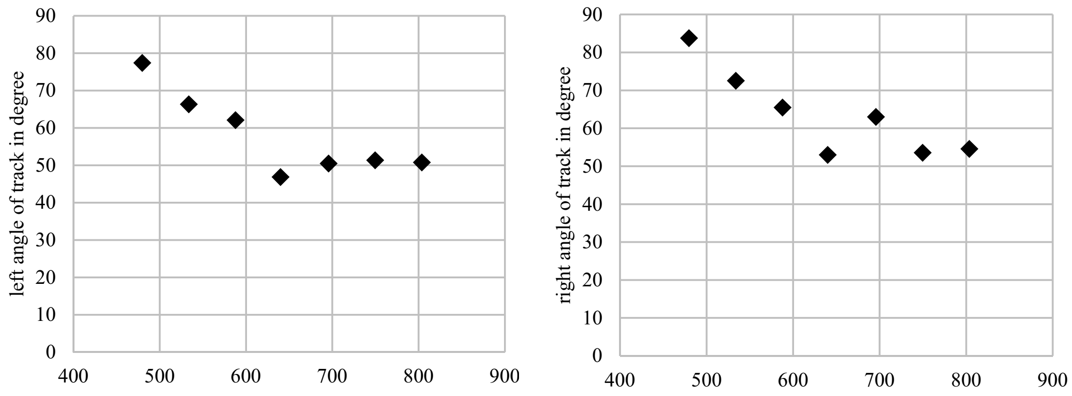

Fig. 6. left: left contact angle in respect to laser power right: right contact angle in respect to laser power.

As described before, about 500 W of laser power was needed to melt the wire. In the range from 500 W to 600 W, 50% of the maximum shape change in height and width was observed. Within this 100 W range different shapes for welding of layers or welding of structures can be achieved. When exceeding 500 W, more of the substrate material will get molten. This results in higher dilutions of the base and depostion materials, which is undesirable.

4. Outlook

Further investigations should target the influence of laser power when welding layers, since due to previous welded track, the melt is not able to flow to both sides evenly. Also, the influence of the scanner parameters have to be investigated. Especially the scan amplitude should show a significant effect on the shapes of the deposit and the molten area, as this parameter changes the heat distribution in the process area caused by the laser radiation.

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