

Investigations on laser metal deposition of stainless steel 316L with coaxial wire feeding

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Abstract

Laser metal deposition with wire formed additional material is an established process in industry for the repair of high value parts. The main disadvantage regarding additive manufacturing of complex shaped parts with commonly used off-axis wire-feeding is the influence of the wire feeding direction on the layer quality. To fulfill the demand of a laser metal deposition process without any directionality a coaxially wire feeding was investigated. In the results of the experimental research the influence of the main process parameters (laser power, velocity and wire feed rate) on the properties of clad tracks made of the stainless steel 316L is presented. Additionally the correlation between working distance and spot geometry and its influence on the process stability is explained. Finally the build-up of thin-wall structures with enhanced surface quality by an adaptation of parameters for achieving a multi-directional process is demonstrated.

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1. Introduction

Due to the demand to increase the process efficiency and operational safety in laser metal deposition wire feeding became more interesting in comparison to powder. The disadvantage of an off-axis wire feeding regarding its dependency of orientation can be solved by a coaxial wire feeding.

Nomenclature

v	feed rate
v_w	wire feed rate
P_L	laser power

2. Laser metal deposition with coaxial wire feeding

The laser metal deposition (LMD) is used to build up 3D parts layer by layer (Gasser et al. 2003). Beside powder formed materials also wire materials can be used as additional material in the LMD process. Therefor the laserradiation heaten up the base material to create a melt pool on the surface. The wire is fed into the melt pool, the interaction zone with the laser radiation, where a thin layer of the base material and the additional material are melted.

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3. Equipment and materials

The experimental investigations were performed with a 5kW fibre-coupled diode laser by Laserline GmbH with beam quality of 30 mm mrad. The cladding optic for coaxial wire feeding was developed by Fraunhofer IWS (Fraunhofer). Stainless steel 316L was used as addition material and low carbon steel as substrate material.

The cladding process with coaxial wire feeding and the schematic process layout is shown in figure 1. The laser radiation is focused with three single beams onto the substrate, where a melt pool shielded by an inert gas is created and the wire is fed into it. After solidification of the melted material a dense layer with fully metallurgical bonding to the substrate is produced.

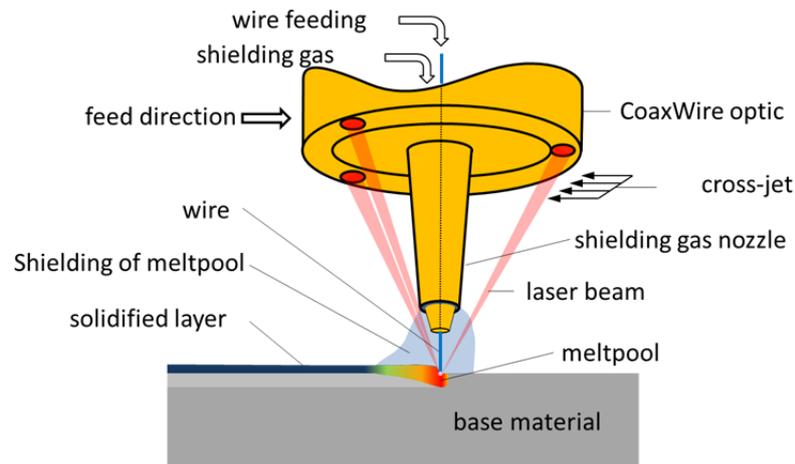


Fig. 1. Schematic cladding process with CoaxWire optics.

4. Results

The influence of the laser power on a cladded single track is shown in figure 2. At a feed rate of 1.2 mm/min and a wire feed rate of 1.9 m/min a laser power of 1.0 kW melts the additional material completely, but bonding failures were detected (s. figure 2 left). An increase of laser power up to 1.4 kW leads to a good bonding and a low dilution rate of less than 10% (s. figure 2 middle). A further increase of the laser power up to 1.8 kW enlarges the dilution and the heat input into the substrate (s. figure 2 right).

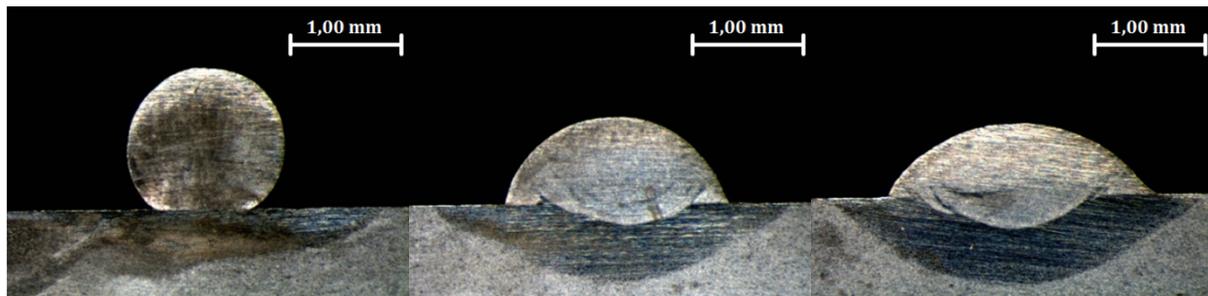


Fig. 2. Cross sections of cladded tracks ($v = 1200\text{mm/min}$; $v_w = 1.9\text{ m/min}$) Left: $P_L = 1.0\text{ kW}$; Middle: $P_L = 1.4\text{ kW}$; Right: $P_L = 1.8\text{ kW}$.

Defocusing the optic by a decrease of the working distance it is possible to clad wider tracks. At a lower feed rate of 0.6 m/min and a laser power of 1.0 kW single tracks can be cladded with nearly no dilution and a fully metallurgical bonding (s. figure 3 left). An enlargement of the laser power to 1.6 kW leads to a larger dilution rate and two burn-ins in the substrate were detected caused by the defocusing.

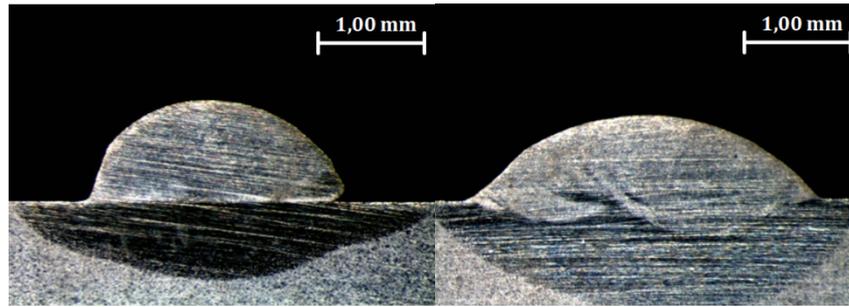


Fig. 3. Cross sections of cladded tracks ($v = 600\text{mm/min}$; $v_w = 1.5\text{ m/min}$) Left: $P_L = 1.0\text{ kW}$; Right: $P_L = 1.6\text{ kW}$.

The feed rate has an influence on the heat input into the base material and on the track high, when the laser power and wire feed rate are kept constant. An increase of the feed rate of 50% from 0.6 m/min up to 0.9 m/min (s. figure 4) decreases the heat affected zone only little, the dilution rate is in the same range of 10%, but the track high decreases from 1.0 mm down to 0.7 mm, which correlates with the smaller amount of additional material per cladded length.

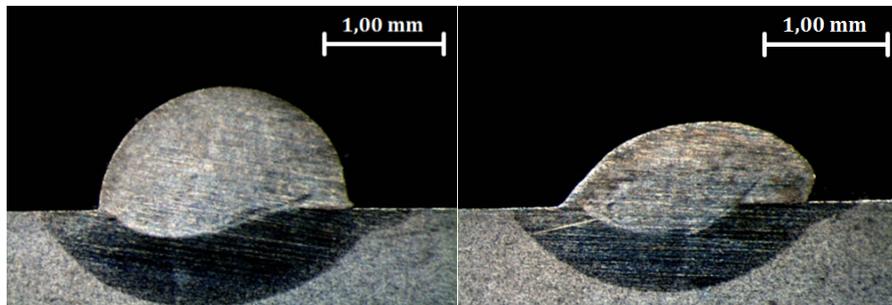


Fig. 4. Cross sections of cladded tracks ($P_L = 1.2\text{ kW}$; $v_w = 1.5\text{ m/min}$) Left: $v = 0.6\text{ m/min}$; Right: $v = 0.9\text{ m/min}$.

The wire feed rate correlates nearly linear with the track high. The energy input which is needed to melt the additional material increases at larger wire feed rates, so the heat input into the base material decreases at higher wire feed rates at constant laser power.

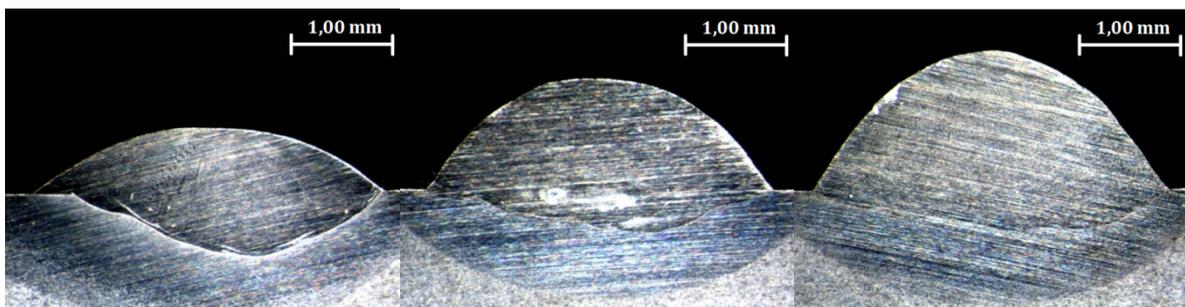


Fig. 5. Cross sections ($v = 0.6\text{ m/min}$; $P_L = 2.5\text{ kW}$) Left: $v_w = 1.5\text{ m/min}$; Middle: $v_w = 2.5\text{ m/min}$; Right: $v_w = 4.0\text{ m/min}$.

After the determination of suitable parameters for a crack-free tracks with nearly 100 % density and a low dilution rate of less than 10%, multilayers consisting of 20 tracks with an overlap ratio of 50 % were produced (s. figure 6 left).

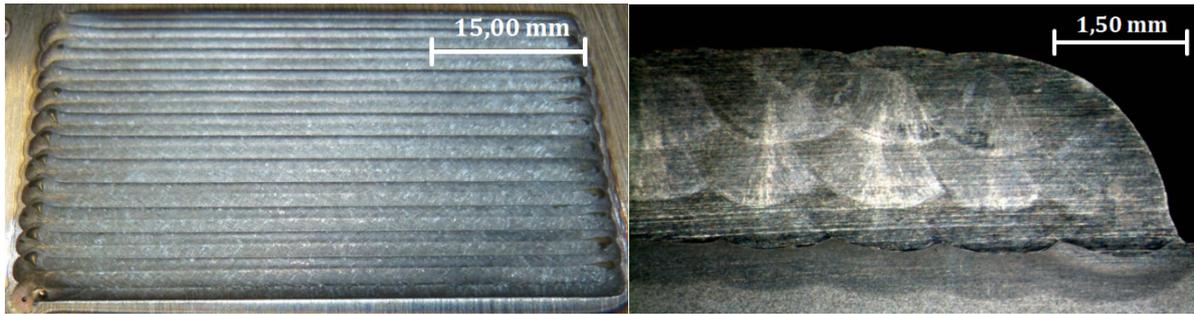


Fig. 6. Cladded layer (left) and cross section (right) $v = 1.2 \text{ mm/min}$; $P_L = 1.8 \text{ kW}$; $v_w = 1.5 \text{ m/min}$.

For manufacturing hollow structures the process parameters were adapted during the build up by a decrease of the laser power to avoid overheating of the growing part during the process. Therefore the laser power is ramped from $P_L = 1.2 \text{ kW}$ down to $P_L = 0.9 \text{ kW}$ in the first 20 layers. For demonstrating the purposes of the coaxial wire cladding process regarding the independency of orientation of wire feeding direction a hollow cylinder made of 100 layers was build up (s. figure 7). The complete build-up time takes 8 minutes.

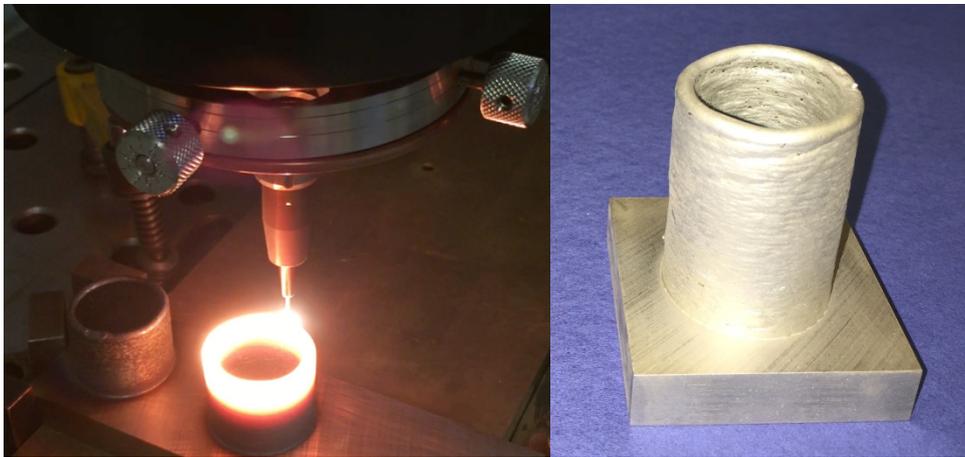


Fig. 7. Additive manufacturing process of hollow cylinder ($v = 1000 \text{ mm/min}$; $P_L = 2.5 \text{ kW}$; $v_w = 1.5 \text{ m/min}$).

5. Conclusions

The CoaxWire optic with its coaxial wire feeding concept is capable of building parts. The investigations of the process parameters laser power, feed rate and wire feed rate shows several correlations between process parameters and layer thickness, dilution rate and size of the heat affected zone. Defect free layers can be cladded with a dilution rate less than 10 %. In comparison to powder feeding the coaxial wire technology revealed advantages like the low amount of wasted material and a higher operational safety without disadvantages like dependency of wire feeding direction in the conventional off-axis wire feeding technology.

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