10th CIRP Conference on
Photonic Technologies [LANE 2018]

Industrial Paper

Investigations on camera based melt pool control for laser metal deposition

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Abstract

Laser metal deposition is an established process in industry for cladding and additive manufacturing applications. The quality of the deposited layers, especially a constant dilution rate and build up height, requires a control of the melt pool size. The laser power has, in comparison to other process parameters, the strongest correlation to melt pool size. Therefore a camera based melt pool monitoring system, which adjusts the laser power in real time, is developed. In the experimental research several difficult to clad parts with varying wall thicknesses are investigated. Especially the increase of the melt pool by heat accumulation and its influence on the dilution rate will be presented in the results. The performance of the system will be demonstrated by the comparison of the controlled and non-controlled process for cladding of thin-walled tubes. Finally some end-user parts, which are not processable without control, will be presented.

Keywords: laser cladding; additive manufacturing; laser metal deposition; melt pool; process control

1. Introduction

In the field of wear and corrosion protection of parts the main demand is to improve the material properties in comparison to the base material by a protection layer. To achieve the best protective performance of the cladding a fully metallurgical bonding and a low dilution rate are required. During the cladding process the dilution rate changes in many cases due to a heat accumulation in the cladded part by the energy input of the laser radiation.

2. Process control in laser cladding

The laser power has the strongest correlation to the melt pool size in comparison to the other process parameter of velocity and powder mass flow (Ocylok 2014). Therefore and due to its quick adjustment in the process it is often chosen as controlled variable. Several technologies for the control of the laser metal deposition were investigated in the past. The temperature measurement of the melt pool by a one-colour-pyrometer by Schmidt (1993) was not successful due to dependency of the material emissivity. Using a Ge-Photodiode for the temperature determination was investigated by Bi. et al. (2006) and the use of a two-colour-pyrometer by Salehi et al. (2006). Both technologies lead to a better layer quality and process stability but had the main disadvantage of the need of calibration to the material and to the optical setup. A camera based system fulfils the demand of a material properties independent control system (Colodrón et al. (2011), Hofman et al. (2012)).

3. Camera based process control

At the first stage of the experiments the melt pool size was monitored by the controller to investigate the correlation of melt pool size to laser power. For the measurement of the melt pool size by the controller the process picture, which is taken by the camera, must be converted to a binary picture in real time first (see Fig. 1 a

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and b). To correlate the measured melt pool size determined by metallurgical analysis of cross sections with the area in the binary picture an adjustment of the brightness and the grey scale value are necessary. The grey scale value influences the amount of pixels, which are counted as melt pool area.

To avoid any errors in the measurement by reflections of the nozzle inside the measurement area is limited to the opening hole of the nozzle (see Fig. 1b).

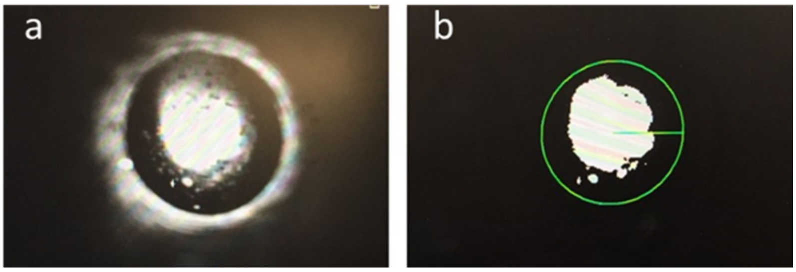

Fig. 1. (a) camera picture of process; (b) binary picture created out of camera picture

The main aim to achieve a fast and stable control of the melt pool an investigation of the controller parameters is necessary. Therefore the proportional, integral and differential terms of the PID-controller are adapted. For the investigations of the controller response time a 30% enlarged laser power starting point was chosen. The final controller parameters of a stable laser power control without fluctuations or overshoots reduces the response time to less than 0.1 sec.

4. Results

The first experiments with laser power control were carried out at stainless steel tubes with varying wall thicknesses sections of 10 mm down to 4 mm. The non-controlled process with constant laser power of 2.7 kW and a monitored melt pool size is used as reference. Due to the larger the heat input an increase of the melt pool area size of approx. 50 % is detected, so the melt pool enlarges its diameter by approx. 23% from 4.3 mm up to 5.3 mm (see Fig. 2a).

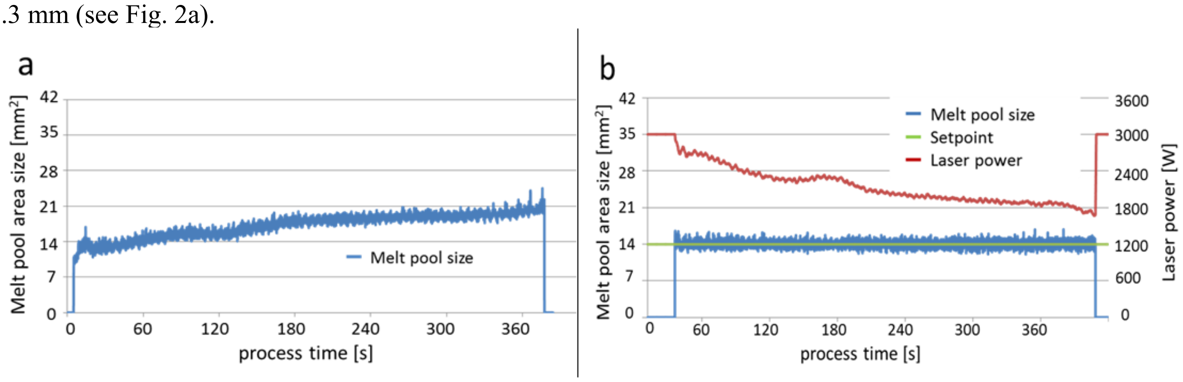

Fig. 2. Melt pool area size (a) non-controlled process; (b) controlled process

The larger heat input during the non-controlled process leads to more oxidation at the surface of the cladded layer (see Fig. 3a). The controlled process provides a consistent layer quality regarding oxidation over the complete cladded area of the part. Caused by the large diameter of the parts in combination with a wall thickness of more than 4 mm the improvement by the controller on the dilution rate is negligible. Both processes deliver a dilution rate less than 10 %.

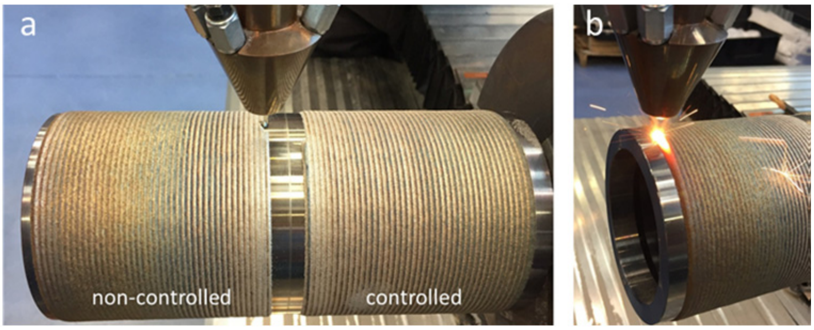

Fig. 3. (a) Comparison of oxidation controlled vs. non controlled process; (b) laser cladding process

To force the effect of heat accumulation more challenging parts of stainless steel tubes with a wall-thickness of 2 mm are cladded. Without process control at a constant laser power of 2.7 kW the melt pool size increases by the factor of two within less than ten turns of the part. The amount of sparks also increases due to the oxidizing of the complete part and the size of the melt pool (see Fig. 4a). The controlled process runs smoothly without any larger amounts of sparks. The laser power is reduced by the control from the original value of 2.7 kW at the starting point down to 1.2 kW, which is a decrease of more than 50%. By use of the controller the heat input is reduced, so the shape of the melt pool is still nearly circular. The elliptical shape of the glowing area (Fig. 4b) is caused by the small cooling rates behind the melt pool and not by the melt pool itself. The melt pool shape changes in the non-controlled process from circular at the beginning to an elongated elliptical shape during processing. Due to the geometry of the tube, non-linear material behavior and the need of a complete cladding with an extensive heat accumulation at the end of the process a prediction how to reduce the laser power by modelling the process is complex and not economical efficient.

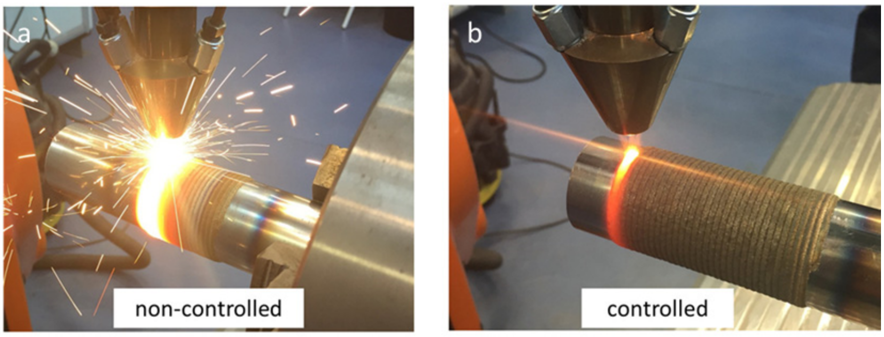

Fig. 4. (a) non-controlled process; (b) controlled process

During the non-controlled process the heat accumulation is increased dramatically, so the process must be stopped when the wall thickness is fully penetrated by the melt pool (see Fig. 5). The surface of the tube is also oxidized in the not cladded area in front of the process, which additionally indicates the large heat input.

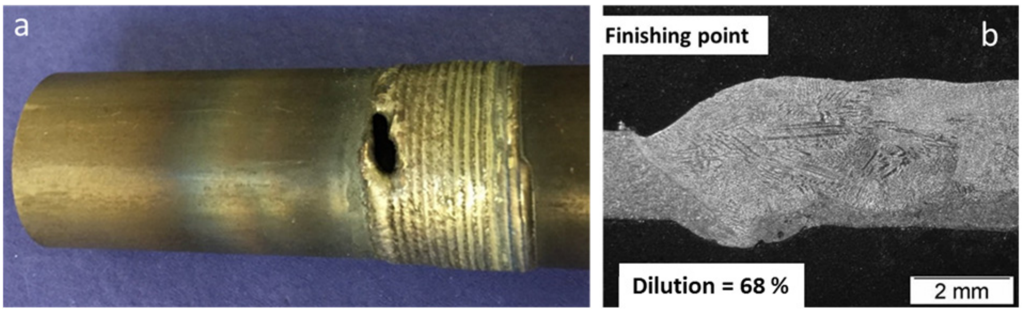

Fig. 5. (a) part after non-controlled process; (b) cross section of completely penetrated area of part

In comparison to the non-controlled process the part can be cladded completely by use of the controller without any cooling interruptions. The dilution rate is constant at a level of approx. 5% from the starting point until the process ends close to the end of the tube.

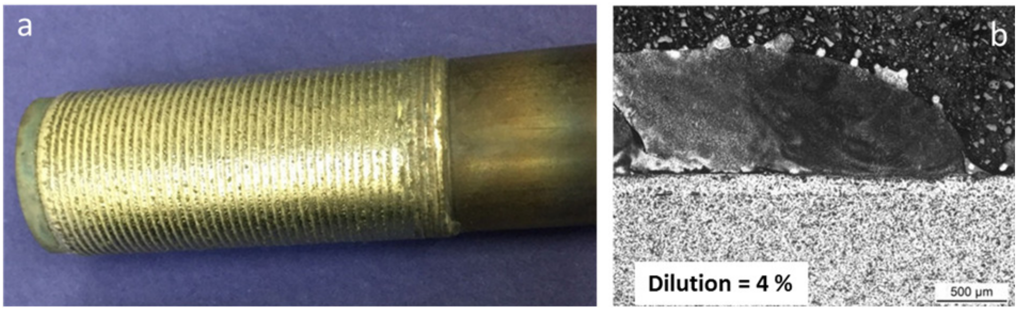

Fig. 6. (a) part after controlled process; (b) cross section with low dilution rate of 4%

Finally the controller is tested under industrial conditions at the facility of TMComas (see Fig. 7a). Therefore a challenging part of a hollow flange geometry out of carbon steel is chosen (see Fig. 7b), which is not processable without any cooling interruptions to ensure the material properties for high temperature applications.

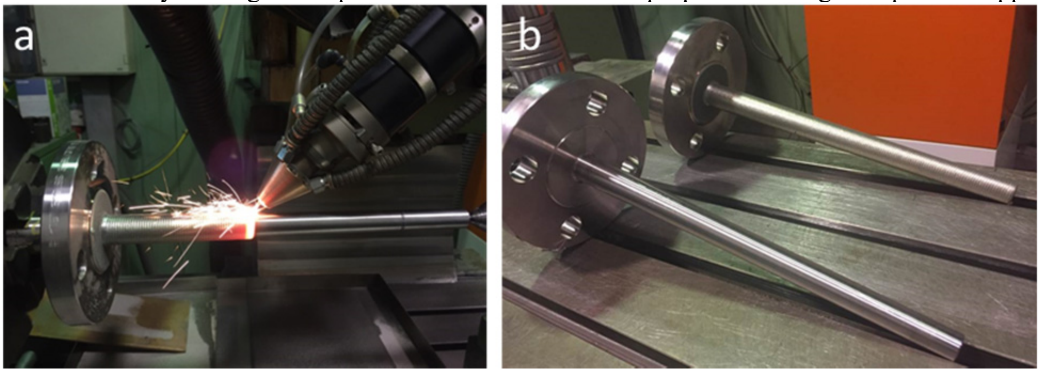

Fig. 7. (a) cladding process of end user parts; (b) completely cladded part

The end user part is cladded completely by the controlled process without any interruptions and with a constant dilution rate of less than 10 %, which was recommended for the cladding.

5. Conclusions

The validation of the melt pool controller, which is developed by Laserline, and tested in the user-case with the partners was successful. The developed process control is suitable to achieve a stable process under challenging conditions like changing heat accumulation and thermal conductivity. The performance of the controller was demonstrated at several parts, e.g. changing wall-thicknesses in tube geometries and thin-walled tubes. As reference trials of the non-controlled process with constant laser power were carried out. For the cladding of thin-walled tube structures the controller is essential to process these parts without any cooling interruptions. The quality of the cladding can be significantly increased regarding less heat input and a smaller constant dilution rate. The potential of a controlled process was demonstrated on mockup parts at IK4Lortek and end-user parts at TMComas, which cannot be processed without control today.

Acknowledgements

This research has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 636902

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