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Process characterization in laser metal deposition of hot work tool steel

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Abstract

Powder based laser metal deposition is a well-established manufacturing process in the field of tool and mould building. The additive manufacturing process is used to repair worn components or to adapt the geometry of existing parts. The central subject of this paper is the process characterization of the hot work tool steel H11 (material number 1.2343). Different beam diameters between 3 and 6 mm are investigated at a constant laser power of 4 kW. The powder mass flow and the feed rate are varied to optimize the degree of dilution. Single deposition tracks and cuboids are used to evaluate the energy input and the deposition rate at different parameter sets. The typical seam parameters are measured in order to characterize the deposition process, define process limits and evaluate the process efficiency.

Keywords: laser metal deposition; hot work tool steel; process efficiency

1. Introduction

Powder based laser metal deposition is a well-established additive manufacturing process in the field of tool or mould building to produce or repair components. To improve the efficiency of powder based laser metal deposition, the following approach is often practiced in industry. To need less time for depositing the filler material on a surface, the target is the reduction of the number of cladding tracks (Tuominen et al. 2003). Therefore, the process parameters should be adapted so that weld tracks of maximum width are obtained. As a result of this, large focal diameter, high supplied power and slow feed rates are applied. This approach to process management entails an enormous input of energy in the component as a consequence of which the component is exposed to very high thermal stress.

Alternative approaches are shown in Erler et al. (2015), Partes et al. (2005) and Schopphoven et al. (2015). The goal was to create a fast and efficient laser metal deposition process using smaller beam diameters and higher feed rates. The central subject of this paper is comparison of both approaches. Therefor the typical hot work tool steel H11 (material number 1.2343) was chosen for the welding experiments and the process characterization.

2. Basics and approach

The energy input per unit length E_L is an indicator of the thermal stress of a part. The energy input per unit length increment can be calculated from the ratio of the supplied laser power P_B to the feed rate v:

$$E_L = \frac{P}{v} \tag{1}$$

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In comparison with conventional welding without filler material, laser metal deposition requires consideration, in addition to the energy per unit length of another characteristic parameter, i.e. the mass per unit length m_L:

$$m_L = \frac{\dot{m}}{v} \tag{2}$$

The mass per unit length characterizes the mass applied per unit length increment and is obtained by the ratio of the powder mass flow $\dot{m}$ to the feed rate v.

$$AG = \frac{A_2}{A_1 + A_2} \cdot 100 \tag{3}$$

Dilution provided another parameter of the quality of the metal deposition weld. It characterizes the degree by which the filler metal dilutes the substrate material (3). The purpose of coating is to obtain a systematic increase in volume. To that end, the cross-sectional area on the substrate A_1 should be maximized and the cross-sectional area in the substrate A_2 minimized. Accordingly, metal deposition of high quality and efficiency have low degrees of dilution of the order of 5 to 30 % (Huegel and Graf 2014).

A fiber-guided disk laser with maximum 4 kW output power was used in combination with a 6-axis articulated robot and the powder-based laser metal deposition package from Trumpf Laser GmbH.

For the variation of the track width, beam diameters from 2,9 up to 5,9 mm were investigated. The laser power was kept constant for each welding experiment at a value of 4 kW, to achieve high feed rates. To adapt the degree of dilution, the mass per unit length was varied for the different beam diameters. After the evaluation of an optimized parameter set for each beam diameter, cuboids with an edge length of 40 mm and a height of 10 mm were generated, to compare the different beam diameters.

3. Experimental setup

The utilized powder-based laser metal deposition package by company Trumpf Laser GmbH is based on a disc laser with a maximum output power of 4 kW. A transport fiber is used to direct the laser radiation to the processing head. The processing head is equipped with motorized focus position adjustment. This means that the diameter of the laser beam can be adapted to the welding task between 0.4 and 7 mm if the powder focus is in a consistent position. The used nozzle was a coaxial three-stream powder nozzle. A 6-axis articulated robot was responsible for the relative movement between welding head and work piece. Additional characteristic parameters of the welding system are listed in table 1:

Table 1. Specifications of Trumpf LMD package.

An example of a column heading	
Type of laser	Trumpf TruDisk4002
Wave length λ [μm]	1.03
Maximum laser power P_B [W] (measured)	4000
Focal diameter d_f [mm] (measured)	2.9, 3.9, 4.9, 5.9
Index of diffraction M^2 (measured)	25
Rayleigh length zr [mm] (measured)	4.3

H11 powder from TLS Technik GmbH, with a particle size form 50 up to 150 μm, was used as filler material.

4. Results and discussion

Table 1 shows the qualified parameter sets for the four beam diameters. The decrease of the beam diameter from 5.9 mm to 2.9 mm was increasing the feed rate for the single tracks from 12.5 to 70 mm/s. This lead, because of the constant laser power, to a lowered energy per unit length and to a smaller energy input inside the component for a single track. But the track width and the track height were reduced around 50 % due to the reduction of the beam diameter.

Table 2. Parameter sets, dilution and build times for cuboids

Beam diameter [mm]	Feed rate [mm/s]	Energy per unit length [J/mm] (single track)	Degree of dilution [%] (single track)	Number of tracks for cuboids	Build time for cuboids [s]
2.9	70	57	11	680	503
3.9	42	95	6	425	516
4.9	25	160	6	260	527
5.9	12.5	320	3	140	564

Therefore, a much higher number of single tracks was required to build up the cuboids using the smallest beam diameter in comparison to the largest. The parameter set with the smallest beam diameter of 2.9 mm showed the shortest build time and the lowest accumulated heat input, if the number of tracks and the energy per unit length are taken in account. The result was a lower thermal stress inside the component and a higher cycle efficiency while building up the cuboids with high feed rates and small beam diameters. Due to the adaption of the mass per unit length for each parameter set, good dilutions between 3 and 11 % were achieved.

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References

Erler, M., Ebert, R., Gronau, S., Horn, M., Klötzer, S., Exner, H., 2015. High Rate Micro Cladding Using a Short Pulsed Fiber Laser, Proc. of 7th International Congress on Laser Advanced Materials Processing. Paper A120.

Hügel, H., Graf, T., 2014. Laser in der Fertigung: Grundlagen der Strahlquellen, Systeme, Fertigungsverfahren (Laser in manufacturing: fundamentals in beam sources, systems, manufacturing processes). 3th Edition, Springer Vieweg, Wiesbaden.

Partes, K., Seefeld, T., Sepold, G., Vollertsen, F., 2005. Increased Efficiency in Laser Cladding by Optimization of Beam Intensity and Travel Speed. Workshop of Laser Applications in Europe, Proc. Of SPIE Vol. 61570O-1

Schopphoven, T., Gasser, A., Wissenbach, K., Poprawe, R., 2015. Investigations on ultra-high-speed laser material deposition as alternative for hard chrome plating and thermal spraying. Proc. of ICALEO, 34th int. Cong. on Applications of Lasers and Electro-Optics, Atlanta, USA, Paper 1601.

Tuominen, J., Hayhurst, P., Eronen, V., Vuoristo, P., Mäntylä, T., 2003. Comparison of multi- feed and off axis high power diode laser (HPDL) cladding, Proc. Of SPIE Vol. 4973, San Jose, CA, USA, p. 116 - 127.