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Experimental study of porosity reduction in high deposition-rate Laser Material Deposition

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ABSTRACT

For several years, the interest in Additive Manufacturing (AM) is continuously expanding, owing to the paradigm shift that new production processes, such as Laser Material Deposition (LMD), provide over conventional manufacturing technologies. With LMD, three-dimensional, complex components out of a wide range of materials can be manufactured consecutively layer-by-layer. Despite the technological advantages of the LMD process, currently achieved deposition-rates of approx. 0.5 kg/h for Inconel 718 (IN 718) remain a major concern in regards to processing times and economic feasibility. Moreover, processing conditions need to be chosen carefully or else material defects can be systematically formed either at the interface separating two adjacent clad layers, at the bonding zone or within the bulk of the layer. In this respect, the effects of powder humidity, laser power, nominal powder particle size, powder morphology and shielding gas flow rate on the porosity in laser deposited single tracks at an increased deposition-rate of approx. 2 kg/h was investigated through experiments. Based on experimental results, several approaches of reducing porosity in high deposition-rate LMD are proposed in this paper.

1. Introduction

Laser Material Deposition (LMD) is a laser cladding based free form Additive Manufacturing (AM) technology that can be used to fabricate functional, three-dimensional components. During LMD, a melt pool on the surface of substrate or a previous layer is generated by high power laser radiation. Simultaneously, powdery additive material is injected into the melt pool with a powder feeding nozzle and melted completely. By moving the working table and/or the laser head, a metallurgical fused bond is formed. Complex parts can be manufactured by overlapping various single layers. LMD provides remarkable benefits over conventional welding processes through defined heat input, leading to an accurate control of solidification and thus microstructure. Due to a very small heat affected zone (HAZ) and non-equilibrium rapid solidification, a fine microstructure can be obtained, leading to superior mechanical properties. However, currently achieved deposition-rates of approx. 0.5 kg/h for Inconel 718 (IN 718) are causing a deferred use in the AM of large scale components. Therefore, the increase of the deposition-rate in LMD is coming more and more into research focus in the course of the last years. Still, when aiming towards higher deposition-rates, material properties remain a major concern. The presence of material defects, particularly pores, in laser deposited material is known to be detrimental to the mechanical properties, such as ultimate tensile strength, yield strength and breaking elongation. Understanding the interdependency of the formation of pores and processing conditions therefore is mandatory when pursuing the use of LMD in AM.

In 2000, previous investigations of Brice et al. [1] conclude that the porosity increases with an increase in powder feeding rate and decreases in hatch width in their studies about the effects of processing parameters on the porosity of laser deposited Ti–6Al–4V. This studies were further extended by Kobryn et al. [2], and they found that gas porosity of Ti–6Al–4V deposits can be decreased by increasing scanning speed and laser power. In 2006, Susan et al. [3] showed that the porosity in 17-4PH and 304L deposits increased by using powder which have a large fraction of hollow particles. In the same year, it was observed in the work of Li [4] that the porosity of Ni-based super alloy GTD-111 can be at certain level decreased by heating the filler powder immediately before deposition process. The formation of pores in mixed WC and Ti powder was investigated by Buza et al. [5] in 2008, and it is assumed that the increase of porosity was due to the impurities of the substrate surface, excessive carrier gas flow, chemical reactions between the WC and Ti powder and oxide layers on particles. The effects of laser power, scanning speed, powder feeding rate and shielding gas flow rate on the porosity in laser deposited IN 718 were systematically analyzed by Ng et al. [6] in 2009. According to

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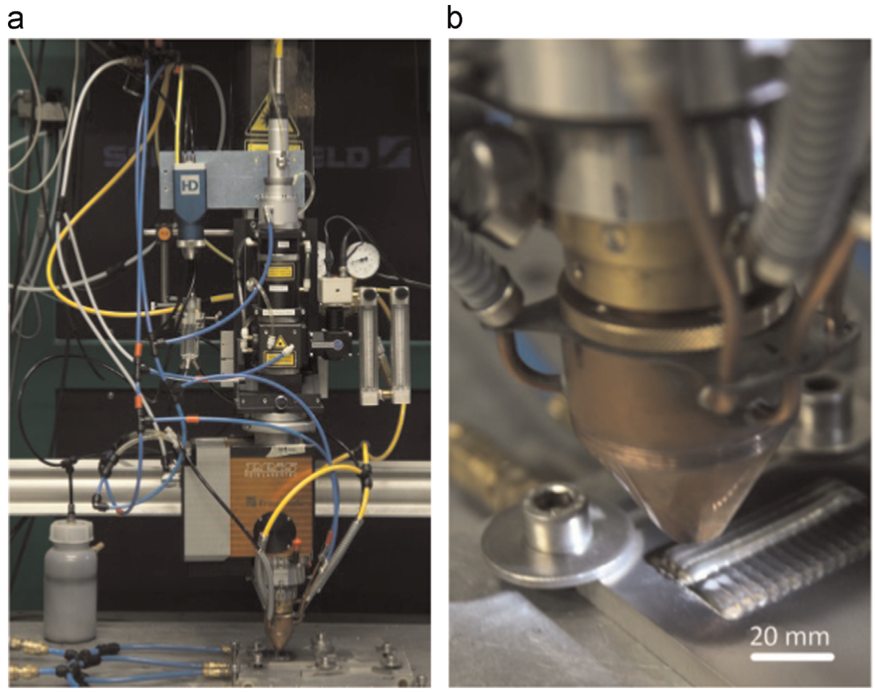

Fig. 1. Experimental setup for high deposition-rate LMD: (a) overview of the experimental setup and (b) detail of ILT-Coax 50 powder nozzle.

Table 1
Nominal chemical composition of IN 718 powder in wt%.

Ni+Co	Cr	Fe	Nb+Ta	Mo	Ti	Al
50–55	17–21	BAL	4.75–5.5	2.8–3.3	0.65–1.15	0.2–0.8

Table 2
Range of process parameters.

P_L (kW)	$\dot{m}$ (kg/h)	v (mm/min)	d_L (mm)	F_{SG} (Nl/min)
3.1 or 4.1	2	1500	4	7.3 to 33

Table 3
Range of process parameters.

Track no.	P_L (kW)	$\dot{m}$ (kg/h)	v (mm/min)	d_L (mm)	F_{SG} (Nl/min)	Drying
1	4.1	2	1500	4	12	Without
2	4.1	2	1500	4	12	With

their investigations: (a) gas porosity increases with an increase in powder feeding rate and shielding gas flow; (b) porosity level increases with increased laser power; (c) scanning speed has no significant influence on porosity. In addition, they conclude that, gas porosity is related to the powder feed rate because the powder stream can trap the shielding gas, which becomes entrained into the melt pool. In summary: (a) both process parameters and powder properties affect the porosity of LMD deposits; (b) for different alloys and (or) different deposition conditions, these influences may be different; (c) effects factors on porosity in high deposition-rate LMD process are not mentioned in most of these previous studies. Last but not least, Witzel et al. [7] investigated

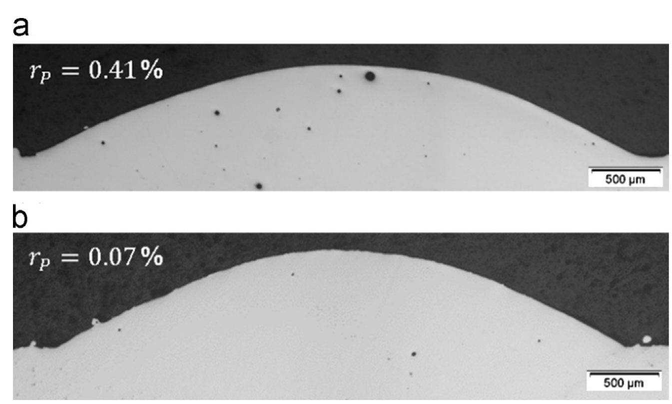

Fig. 2. Cross-sections of deposited tracks: (a) cross-sectioned track deposited with powder without drying treatment and (b) cross-sectioned track deposited with powder with drying treatment.

Table 4
Range of process parameters

Track no.	P_L (kW)	$\dot{m}$ (kg/h)	v (mm/min)	d_L (mm)	F_{SG} (Nl/min)
1	2.1	2	1500	4	12
2	3.1	2	1500	4	12
3	4.1	2	1500	4	12

the material properties in relation to pores distribution on LMD of IN 718 with deposition rates to approximately 3.5 kg/h. However, the effects factors on porosity in high deposition-rate LMD process were not mentioned in their study. Thus, the focus of the current work is to investigate the effect factors on the porosity and approaches of reducing porosity in high deposition-rate LMD.

IN 718 is a niobium-modified nickel-based super alloy, which is widely used in aircraft engine industries for critical rotating parts,