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Effects on part density for a highly productive manufacturing of WC-Co via Laser Powder Bed Fusion

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Abstract
The additive manufacturing of parts made from difficult-to-weld materials through the usage of preheating temperatures of up to $\Theta_0 \leq 500$ °C is enabled by newest L-PBF machine tools, such as the RenAM 500Q HT from the company RENISHAW PLC, Wottun-under-Edge, UK. This work aims to delevop processing parameters for the dense and crack-free manufacturing of tungsten-carbide cobalt (WC-Co) via this off-the-shelf machine tool. Therefore the laserpower and scanning speed were varied between 80 W $\leq P_L \leq$ 350 W and 140 mm/s $\leq v_S \leq$ 650 mm/s respectively. Furthermore the influence of a continuous and pulsed laser mode was analysed. A focus was set on the identification of parameters that enable a highly productive manufacturing while maintaining a high part density. A parameter set for relative density $\rho_{rel.} > 94$ % and a buildup rate $\dot{v} = 0.59$ mm³/s was developed.

additive manufacturing, laser powder bed fusion (L-PBF), cemented carbide, high temperature processing

1. Introduction

The high hardness and toughness of cemented carbides such as tungsten-carbide cobalt (WC-Co) has yet to be fully exploited for the manufacturing via additive technologies [1]. Possible fields of application lie in the lightweight or near net-shape production of wear parts, cutting tools and electrodes for electrical discharge machining (EDM) [2, 3, 4].
In order to produce crack-free and dense parts, so far slow scanning speeds v_S, specialised machine tools with high preheating temperatures $\Theta_0 > 500$ °C or a multi exposure strategy were investigated [3, 5, 6].
This studies aims to overcome the challenges of part cracking and low productivity by applying advaved processing strategies on a highly productive state-of-the-art machine tool with a preheating temperature of $\Theta_0 = 500$ °C.

2. Experimental procedures

In order to investigate the effects on relative density $\rho_{rel.}$ of the WC-Co parts produced via Laser Powder Bed Fusion (L-PBF), cubic samples of 10 mm x 10 mm x 10 mm were manufactured on a RenAM 500Q HT machine device from the company RENISHAW PLC, Wottun-under-Edge, UK. These cubic samples were analyzed with a PLS 1200-3A precision scale from the company KERN UND SOHN GMBH, Balingen-Frommern, Germany, using the archimides method of density measurement.

2.1. Powder material

For this investigation agglomerated and pre-sintered WC-Co 83-17 powder from the company OERLIKON METCO, Pfaffikon, Switzerland, was used. The particle size distribution was measured in accordance with ISO 13322-2 using the optical part measurement system CAMSIZER X2 from the company MICROTRAC RETSCH GMBH, Hahn, Germany [7]. Figure 1 shows the fractions p_3 and the cumulative distribution Q_3 of the processed powder.

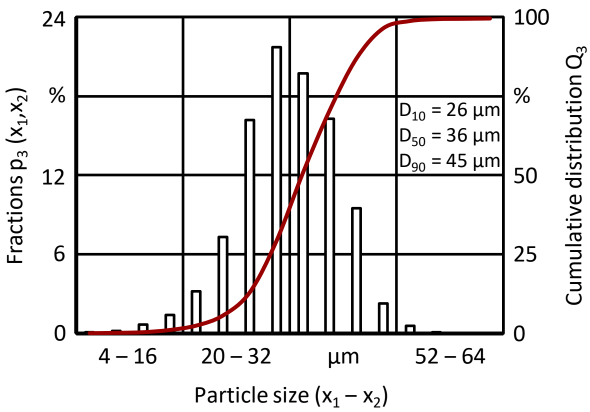


Figure 1. Particle size distribution of WC-Co 83-17 powder

2.2. Processing Parameters

During this investigation, the laser power P_L and the scan speed v_S were varied, while the layer thickness D_S, hatch spacing h_S and preheating temperature Θ_0 were kept constant. Table 1 shows an overview of the processing parameters as well as their respective values. Furthermore the laser mode was varied between a continous and a pulsed operation. For the pulsed operation the point distance x_P and exposure time t_E were varied between 30 µm $\leq x_P \leq$ 65 µm and 100 ms $\leq t_E \leq$ 210 ms respectively.

Table 1. Processing parameters

Parameter		Value
Laser power	P_L	80 – 350 W
Scan speed	v_S	140 – 650 mm/s
Layer thickness	D_S	30 µm
Hatch spacing	h_S	30 µm
Preheating temperature	Θ_0	500 °C
Laser spot size	d_S	75 µm

3. Experimental results

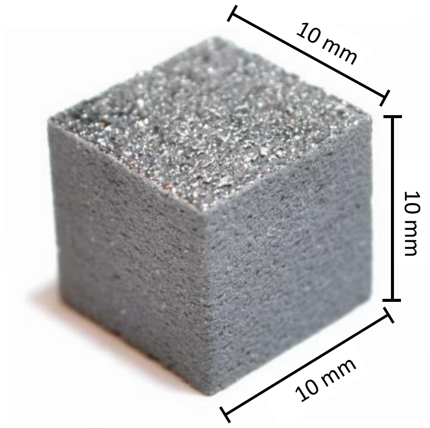
The relative density $\rho_{rel.}$ is an important factor in order to verify the quality of a produced part. Figure 2. shows the relative density $\rho_{rel.}$ of the manufactured cubic samples depending on the volume energy density E_V and the buildup rate $\dot{v}$. Equation 1 and Equation 2 show the calculation of these parameters [7].

$$E_V = \frac{P_L}{\dot{v}} \quad (1)$$

$$\dot{v} = v_S * h_S * D_s \quad (2)$$

For a volume energy density $222\ J/mm^3 \leq E_V \leq 667\ J/mm^3$ a relative density $\rho_{rel.} > 78\ \%$ with a maximum of $\rho_{rel.;max.} > 96\ \%$ was achieved. Except for three outliers, an increase in volume energy density E_V led to a proportional increase of the respective relative density $\rho_{rel.}$ for both, a continuous and a pulsed laser mode. Using the pulsed laser mode, the two specimen that were manufactured with short exposure time t_E and a high laser power P_L had significantly higher relative densities $\rho_{rel.}$ than specimen with a similar volume energy density E_V but longer exposure times t_E and lower laser powers P_L. During the investigation, parts with a volume energy density $E_V > 667\ J/mm^3$ were manufactured, however they were either geometrically inaccurate or completely destroyed while the other ones showed no sign of cracks.

For a buildup rate $0.25\ mm^3/s < \dot{v} < 0.40\ mm^3/s$ a high relative density of $\rho_{rel.} > 88\ \%$ was achieved, however it was also shown, that a high relative density of $\rho_{rel.} > 94\ \%$ can also be achieved for a high buildup rate of $\dot{v} = 0.59\ mm^3/s$. While the continuous laser mode shows a local optimum for the buildup rate $\dot{v}$ in regard to the achievable relatve density $\rho_{rel.}$, the results of the pulsed laser show no clear tendency. Further investigations in regard to the variation of the exposure time t_E and the point distance x_P between each exposure x_E are needed.

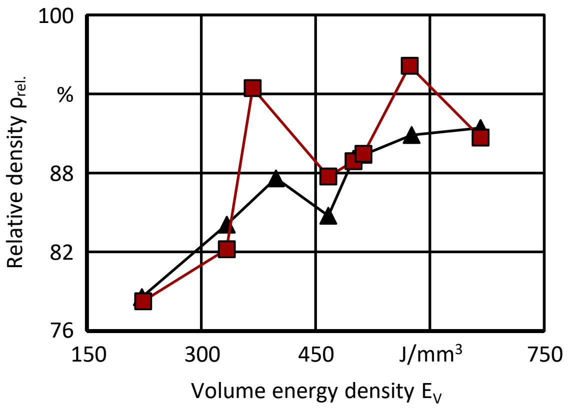


Machine tool:
RenAM 500Q HT, Renishaw plc

Material:
WC-17%Co

Process parameter:
D_S = 30 µm
h_S = 30 µm
Θ_0 = 500 °C

Laser mode:
continious
pulsed



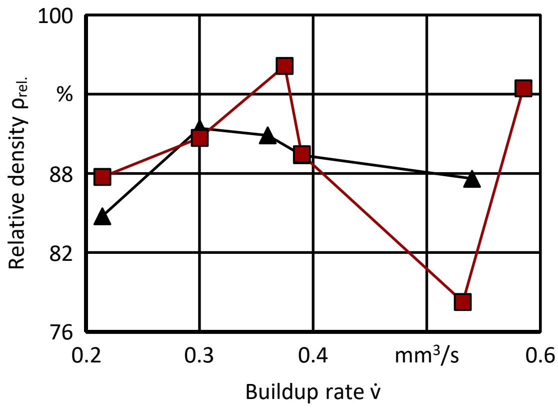


Figure 2. Relative density $\rho_{rel.}$ in dependency of the volume energy density E_V and the buildup rate $\dot{v}$ with respect to the laser mode

4. Conclusion and outlook

The findings of this ongoing research show, that it is possible to manufacture parts with a relative density $\rho_{rel.} > 94\ \%$ while still maintaining a high productivity. The preheating temperature of $\Theta_0 = 500\ °C$ shows promising results in producing crack-free WC-Co parts. Both, continuous and puled laser modes were capable to gain high part quality. A higher volume energy density E_V will lead to an increase of the relative part density $\rho_{rel.}$ up to a limit of $E_V \leq 667\ J/mm^3$ after which the manufactured parts were destroyed.

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