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Additive Manufacturing of precision cemented carbide parts

J. Polte[1], M. Polte[1,2], C. Lahoda[2], T. Hocke[2], E. Uhlmann[1,2]

[1]*Fraunhofer Institute for Production Systems and Design Technology IPK, Germany*
[2]*Institute for Machine Tools and Factory Management IWF, Technische Universität Berlin, Germany*

Toni.hocke@iwf.tu-berlin.de

Abstract
Cemented carbide parts are commonly used as wear resistance components in a broad range of industry, e.g. for forming, mould making and matrices. At state of the art the machining of precision cemented carbide components by milling is strongly limited due to excessive tool wear and long machining times. Promising approaches for precision machining of cemented carbide components are dedicated cutting tool coatings, new cutting materials like binderless polycrystalline diamond and ultrasonic-assisted machining. Nevertheless, for all these approaches the components need to be machined of monolithic materials. The new approach addresses an innovative manufacturing process chain composed of near net shape Additive Manufacturing followed by a precision finishing process. Within this investigations for the manufacturing of precision cemented carbide parts, cemented carbide with a cobalt content of 17 % and a grain size in a range of 23 µm ≤ g_s ≤ 40 µm were used. As Additive Manufacturing technology laser powder bed fusion was used. Diamond slide burnishing and immersed tumbling were investigated as finishing technologies. Based on the investigations, a dedicated process chain for the manufacturing of precision cemented carbide parts could be realised. The findings show that the developed process chain composed of near net shape Additive Manufacturing and the finishing process diamond slide burnishing enables the manufacturing of precision cemented carbide parts with a geometrical accuracy of a_g ≤ 10 µm. Due to the finishing process the initial surface roughness after Additive Manufacturing could reduce by Ra = 89 %.

additive manufacturing, immersed tumbling, diamond slide burnishing, precision finishing

1. Introduction

Additive Manufacturing (AM) enables the production of highly complex metal components with maximum geometric flexibility in lightweight construction. These manufacturing processes are limited concerning the achievable surface roughness values of 5 µm ≤ Ra ≤ 15 µm, the geometrical accuracies a_g ≤ 1 mm and the residual stress condition. Fundamentally, additively manufactured components suffer from tensile residual stresses σ_E, which result in relevant distortion during the post-processing. The current state of the art shows no established precision finishing method, which addresses the geometrical accuracy a_g, the surface roughness value as well as the residual stress condition according to the application. Due to increasing requirements from industry regarding additively manufactured parts, innovative process chains need to be developed [1]. For manufacturing cemented carbide parts of forming tools, moulds and matrices powder bed based processes like the laser powder bed fusion (LPBF) are established [2, 3]. The new approach addresses an innovative manufacturing process chain composed of near net shape Additive Manufacturing followed by a dedicated precision finishing process. As finishing technologies diamond slide burnishing (DSB) and immersed tumbling were investigated.

2. Experimental Setup

For manufacturing precision cemented carbide parts a dedicated process chain composed of near net shape Additive Manufacturing by LPBF followed by a precision finishing process was investigated. As finishing technologies DSB and immersed tumbling were analysed in correlation to LPBF. Cemented carbide with a cobalt percentage of 17 % and a grain size in a range of 23 µm ≤ g_s ≤ 40 µm were used as part material. The investigated process parameters for LPBF are shown in Table 1.

Table 1. Investigated LPBF process parameters

Parameters	Part 1	Part 2	Part 3	Part 4	Part 5
Pre-heating h_p	500 °C	500 °C	500 °C	500 °C	500 °C
Laserpower p_L	310 W	119 W	80 W	100 W	80 W
Energy density ρ_E	1,722 J/mm³	224 J/mm³	213 J/mm³	333 J/mm³	222 J/mm³
Speed v_L	0.2 m/s	0.59 m/s	0.42 m/s	0.33 m/s	0.4 m/s
Pulsation p_u	Const.	Pulsed	Pulsed	Pulsed	Const.
Point distance l_P	4 µm	65 µm	50 µm	40 µm	8 µm
Exposure time t_E	20 µs	110 µs	120 µs	120 µs	20 µs

For the LPBF process the machine tool RenAM 500 Q HT of the RENISHAW GMBH, Pliezhausen, Germany, was used. The DSB of the near net shape LPBF parts were carried out on the 5-axis-high-precision-machine tool HSC MP7/5 of the company EXERON GMBH, Oberndorf, Germany, with a dedicated tool made of single crystal diamond with a radius of r = 1.5 mm from the company BAUBLIES AG, Renningen-Malmsheim, Germany. The four lapping media HSC 1/500, HSC 1/300, QZ and M 5/400 were applied for the investigation of the immersed tumbling process on the machine tool DF-3 Tools of the OTEC PRÄZISIONSFINISH GMBH, Straubenhardt, Germany. The measurements of the surface roughness values and geometrical accuracies a_g of the machined parts were done on the contour and surface roughness measurement device nanoscan 855 of the company JENOPTIK AG, Jena, Germany.

3. Experimental investigations

Within the investigation of the Additive Manufacturing process chain for manufacturing precision cemented carbide parts composed of LPBF and a dedicated finishing process two different finishing technologies were evaluated, see Figure 1.

As a result of the investigations concerning Additive Manufacturing the cemented carbide parts showed different specific properties regarding the surface roughness Ra and density ρ, which were considered in the evaluation process. To gain fundamental knowledge about the influence of the material part conditions regarding the finishing process, the parts with the highest and lowest surface roughness values were selected for the investigation of DSB. Correllating to Table 1 specimens of class 'part 1' showed a surface roughness of Ra = 11.43 µm paired with a density ρ = 15.019 g/cm³ and specimens of class 'part 5' of Ra = 13.41 µm paired with ρ = 13.123 g/cm³ after LPBF. For the DSB experiments a process force in a range of 80 N ≤ f_p ≤ 140 N was applied.

investigated. Therefore, four lapping media QZ, HSC 1/500, HSC 1/300 and M 5/400 were evaluated. Thereby, the process parameters of the LPBF process showed no significant influence on the process results. For this purpose, the part with the highest surface roughness of Ra = 15.16 µm was used. The results of the investigations are shown in Figure 1 c) and Figure 1 d). It can be determined that the lapping media QZ and M 5/400 led to an improvement of the surface roughness values compared to the lapping media HSC 1/300 and HSC 1/500. Using the lapping medium M 5/400 a reduction of the surface roughness of approximately 30 % with Ra = 10.61 µm after a process time of t_B = 240 min could be achieved (Figure 1 c)). Additional experiments concerning the geometrical accuracy a_g

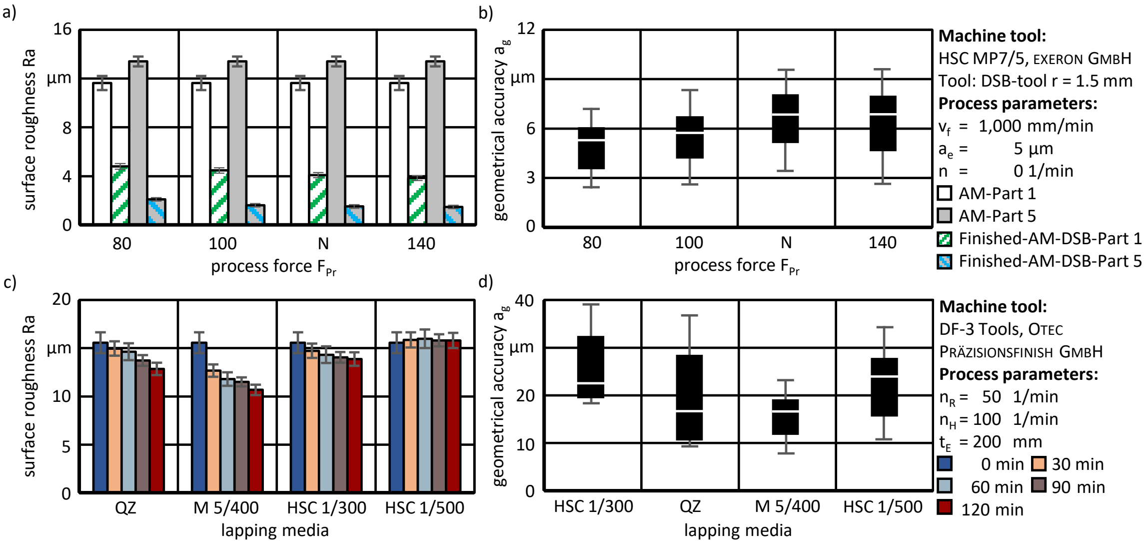

Figure 1. Results for finishing processes concerning surface roughness Ra and geometrical accuracy a_g

In general, the findings show that the surface roughness values of LPBF machined parts made of cemented carbide can be drastically decreased by DSB. It could be determined that the surface roughness values decreases with an increased process force f_p. The results of the investigations show a great influence of the initial specimen condition after LPBF on the DSB process. In general, specimens with lower density ρ paired with higher surface roughness values result in lower surface roughness values after DSB. Using the DSB for specimens of class 'part 5' the surface roughness could be reduced from Ra = 13.41 µm to Ra = 1.48 µm, which correlates to a reduction of the surface roughness Ra of 89 %. Regardless of the set of LPBF process parameters a penetration depth t_E with a geometrical accuracy of a_g ≤ 10 µm for each process force f_p was achieved during the DSB. According to the results it could be proven that DSB enables a high-precision finishing of LPBF parts made of cemented carbide, which results in an innovative process chain (Figure 2).

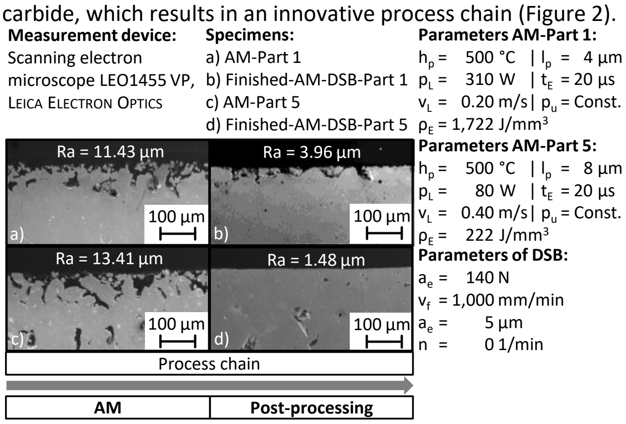

Figure 2. SEM images of the cross sections of the dedicated process chain composed of Additive Manufacturing followed by the DSB

As second approach for precision finishing of LPBF parts made of cemented carbide the immersed tumbling process was

showed depending on the lapping media a significant spread of the results. The highest geometrical accuracy of a_g ≥ 25 µm was achieved using the lapping medium M 5/400 (Figure 1d)). However, the immersed tumbling enables a more time-efficient process due to the ability to machine several parts simultaneously. This advantage can only be used for applications with geometrical accuracies of a_g ≥ 25 µm and surface roughness values of Ra ≥ 10 µm.

4. Conclusion and further investigations

The findings show a great interdependency of the LPBF process parameters and the related finishing process. For the LPBF process a suitable set of process parameters for a near net shape manufacturing of cemented carbide parts could be identified. The results for the investigation of the two finishing processes DSB and immersed tumbling show a great applicability for precise finishing of cemented carbide parts. Especially the DSB process enables high precision with an achievable geometrical accuracy of a_g < 10 µm and a surface roughness of Ra = 1.48 µm. Within the investigations the surface roughness values could be reduced by Ra ≤ 89 %. As a result a dedicated process chain composed of near net shape Additive Manufacturing by LPBF and DSB could be successfully developed. In further investigations, the correlations of the LPBF parameters and the finishing technologies on the residual stress σ will be analysed.

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