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Development of a machining strategy for diamond slide burnishing burnishing tools made of polycrystalline diamond (PCD)

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Abstract
High demands on product quality force companies to reduce production costs. Due to the growing international competition, optical surfaces for tool and mould making need to be produced economically. These surfaces are commonly produced using ultra-precision cutting. However, the efficiency is limited due to low feed velocities v_f, small depth of cut a_p and associated long process times t_{Pr}. An innovative manufacturing process represents diamond burnishing, which can be carried out directly after the high-precision milling process. For this purpose, super-hard materials made of single crystalline diamond (SCD) are currently used as tool materials. Since the material costs are high and the availability is limited, SCD needs to be substituted. An innovative substitution material is polycrystalline diamond (PCD). Within this paper, a machining strategy for the high-precision production of PCD spheres for diamond slide burnishing tools is presented. The processes grinding, polishing and electrical discharge machining (EDM) were applied. Therefore, the manufacturing costs, the surface roughness, the shape accuracy as well as the concentricity accuracy were analysed. Based on these investigations, an efficient and economical machining strategy for the production of high-precision spherical geometries made of PCD can be provided. First results showed that the prefered machining strategy uses a cross-process chain consisting of grinding and polishing. Thereby, the advantages of both processes with the fast manufacturing of the macro-geometry by the grinding process as well as the high surface qualities, which can be achieved by the polishing process, are combined.

Keywords: burnishing, polycrystalline diamond (PCD), shape accuracy, surface roughness

1. Introduction

Diamond slide burnishing (DSB) can be used to produce economically optical surfaces. During this process, a fixed hard sphere is pressed into the surface of the workpiece and guided over the surface with a defined process force F_{Pr} without any rotational movement. The surface roughness can be reduced by more than 90 % [1]. The advantages of using diamond as tool material are the high hardness H, the high resistance against abrasive wear and the low coefficient of friction μ [2]. The high hardness H of polycrystalline diamond (PCD) offers optimum conditions for the production of workpieces with low arithmetical mean deviation Ra. Currently single crystalline diamond (SCD) is successfully used for diamond burnishing. Due to the high material costs, SCD needs to be replaced by PCD. The machinability of PCD and the economic manufacturing of spheres need further knowledge about the processes. However, the machinability of PCD with the aim of producing spheres has not been sufficiently investigated. Futhermore, the grinding, polishing and electrical discharge machining (EDM) were analysed. The manufacturing costs C_M, the arithmetical mean deviation Ra, the shape accuracy T_S as well as the concentricity accuracy T_C were considered for each machining process.

2. Experimental setup

According to the results of Polte [3], a PCD material with an average grain size of $0.5\ \mu m \leq D_{Ko} \leq 1.0\ \mu m$ was used for this investigation to produce best surfaces of the PCD-spheres. For each manufacturing process, a sphere geometry with a radius of $r_S = 0.9$ mm and an azimuth angle of $\alpha = 90°$ was produced. Figure 1 shows the PCD-tool geometry parameters.

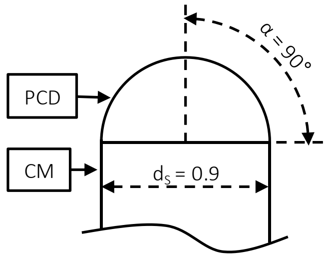


Figure 1. PCD-tool geometry parameters

Due to the manufacturing process, a PCD layer is applied to a carbide metal (CM) substrate and thermally separated from a PCD-CM-plate as circular blanks. The PCD layer thickness on the blank was $t_{PKD} = 1$ mm. The chemical composition was examined with a scanning electron microscope (SEM) of the type Leo 1455 VP from Carl Zeiss AG, Oberkochen, Germany, using energy dispersive X-ray spectroscopy (EDX). In addition, corresponding SEM images of the machined surfaces were taken. The stoichiometric composition is given as a percentage of mass $m_{\%}$ for each element. The carbon (C) content is $m_{\%,C} \approx 66.14$ %, the cobalt (Co) concentration is $m_{\%,Co} \approx 27.24$ %, the oxygen (O) level is $m_{\%,O} \approx 0.55$ % and the tungsten (W) content is $m_{\%,W} \approx 6.07$ %. The elements carbon and cobalt are to be expected. In addition, the elements oxygen and tungsten appear in small quantities. The oxygen input is less than one percent and can be explained by oxidation processes in the edge view due to thermal separation. The tungsten input can be reasoned by the use of the CM substrate.

In order to enable the machining of the PCD blank, it was bonded to a carbide metal shaft by high-vacuum soldering (HVS). A HOMMEL-ETAMIC nanoscan 855 from JENOPTIK AG, Jena, Germany was used to measure the arithmetical mean deviation Ra. The measurement of the shape accuracy T_S as well as the concentricity accuracy T_C was carried out with the measurement device O-Inspect 442 from CARL ZEISS INDUSTRIELLE MESSTECHNIK GMBH. On a Vertex 1F from the company GF MACHINING SOLUTIONS GMBH, Geneva, Switzerland, EDM machining was carried out. For this purpose, a wire electrode with a diameter of d_{we} = 0.1 mm made of CuZn36 and coated with Zn was used. Grinding was executed on a RG5 from COBORN ENGINEERING CO LTD., Romford, Great Britain. A grinding wheel with a ceramic bond and a diamond grain size of d_D = 35 µm was used. The polishing process was carried out on a PG3 from the same company COBORN ENGINEERING CO LTD., Romford, Great Britain.

3. Results and discussion

3.1. Manufacturing costs

The manufacturing costs C_M quantify costs such as the creation of a machining program. Recurring costs per component such as the machine cost rate are also integrated. Grinding is the most cost-effective method with costs of $C_{M,G}$ = 88 € per workpiece. The EDM process has production costs of $C_{M,EDM}$ = 170 € and the costs for the polishing process are $C_{M,P}$ = 122 €. The results are presented in Figure 2. For the polishing process, a cross-process chain including grinding and polishing were used.

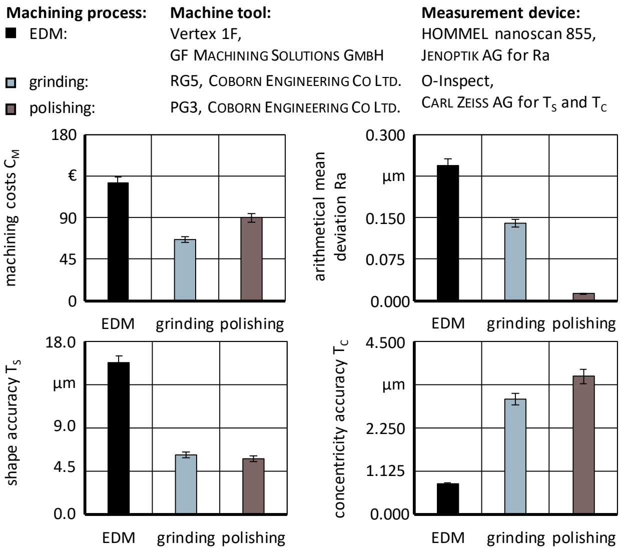


Figure 2. Comparison of the machining processes

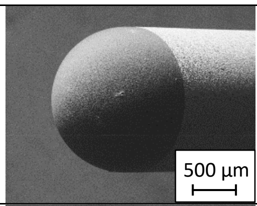
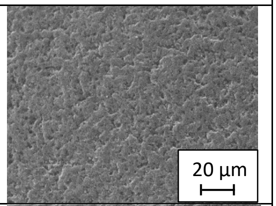
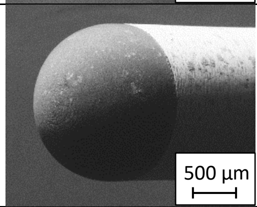
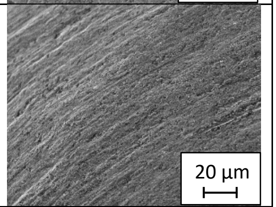
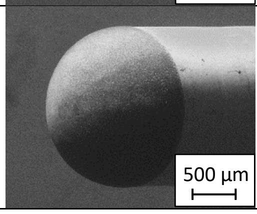
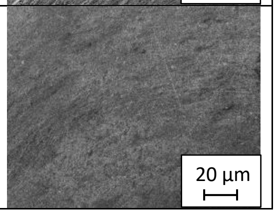
3.2. Machined surfaces

Table 1 shows the SEM images of the processed surfaces. The surface of the EDM process has a rough though regular structure. This surface structure is typical for EDM workpieces. The ground surface shows grooves and scores, which show a uniform radial expression along the centre axis of the PCD diamond slide burnishing head (DSB head). Compared to the surfaces described above, the polished surface shows only minimal scratches and no machining direction can be detected.

3.3. Geometrical investigations

The arithmetical mean deviation Ra, the shape accuracy T_S and the concentricity accuracy T_C were investigated and the results are showen in Figure 2. The analysis of the arithmetical mean deviation Ra shows that the best results were achieved with the polishing process. The arithmetical mean deviation is about Ra = 0.013 µm. The measured values confirm the observations from the analysis of the SEM images. The best results for the shape accuracy T_S could be achieved with the machining process polishing. A shape accuracy of T_S = 5.8 µm could be achieved. An examination showed that the lowest concentricity accuracy of T_C = 0.8 µm could be achieved with the EDM-process.

Table 1 SEM image of machined surfaces

	DSB head	surface of the PCD
EDM		
grinding		
polishing		

4. Conclusion and outlook

The aim of this contribution is the development of an efficient and economical machining strategy for manufacturing of PCD spheres for diamond slide burnishing tools. A low arithmetical mean deviation Ra and low shape accuracy T_S are most important to produce optical surfaces using burnishing. A cross-process chain of grinding and polishing could be evaluated as preferring machining strategy. Thereby, the advantages of both processes with the fast manufacturing of the macro-geometry by the grinding process as well as the high surface qualities by the polishing process, are combined in a target-oriented way. An arithmetical mean deviation of Ra = 0.013 µm, a shape accuracy of T_S = 5.8 µm and a concentricity accuracy of T_C = 3.6 µm could be achieved. Further investigations will examine the machinability of varying tool geometries. This work is supported by the funding program Zentrales Innovationsprogramm Mittelstand (ZIM) by the Federal Ministry for Economic Affairs and Energy (BMWI).

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