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Cutting characteristics of electroplated diamond tools with laser-generated positive clearance

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ABSTRACT

Conventional grinding wheels and dressing tools suffer from problematic chipping conditions at the abrasive grains, caused by near-zero or negative clearance angles at the micro-cutting edges. This paper introduces electroplated diamond dressing tools with positive clearance angles, generated by ultrashort pulsed laser ablation. A series of generic dressing experiments with varying parameters on vitrified bond corundum grinding wheels and long-term tests are presented for a comparative performance assessment of laser-conditioned and conventionally prepared tools. The results are applied to an analysis of the interdependency between the topography of the abrasive layer and the cutting characteristics of dressing tools.

1. Introduction

Grinding of complex workpiece profiles with high accuracy and at high productivity is one of the most critical processes in various industrial applications such as gear manufacturing or fabrication of turbine vanes in the aerospace or energy industry. In addition to the requirements of profile accuracy and durability, the surface integrity of the ground workpiece is a decisive criterion to assess the quality of the part produced. This property is mainly determined by the topography of the applied grinding wheel, which is in turn the result of the dressing process and topographic characteristics of the dressing tool. While a high profile accuracy of commonly used mono-layered electroplated diamond dressing wheels can be achieved by conventional mechanical touch dressing (diamond against diamond), the capabilities of such processes to influence the wheel topography at the grain level are limited.

The scope of the presented work is to demonstrate the capabilities of advanced laser touch-dressing processes to produce a wheel surface with positive clearance angles on individual diamond grains as well as to characterise the topography and the cutting performance of the corresponding tools.

2. State of research

It is emphasised by Salje and Harbs [1] that the conditioning operation of a grinding or dressing tool is one of the key elements within the grinding process chain. Consequently, extensive research into various aspects of conditioning is found in literature [2]. While current research on conventional mechanical processes is mainly focussed on modelling, several experimental studies on alternative conditioning processes such as laser conditioning can be found. Westkämper [3] is one of the first to apply high-powered solid-state lasers to process grinding tool surfaces. Subsequent investigations on super-abrasive wheels mainly deal with the use of lasers to sharpen the wheel by selective ablation of the bond material [4,5]. The availability of high-powered, short and ultrashort pulsed laser sources with near diffraction limited beam quality opens up a number of new approaches to laser-based tool conditioning, for example processing individual superabrasive grains and grain structures for touch dressing of electroplated diamond dressing rolls presented in [6] and profiling of high-strength bonded cubic boron nitride (CBN) grinding tools shown in [7]. It was demonstrated that the short energy–material interaction time with these lasers allows processing heat-sensitive diamond or CBN materials without significant crystallographic transformation of the abrasive grains. The lack of processing forces and the wear-free nature of laser processes are frequently named advantages, promising higher precision when processing ultrahard materials. Accordingly, pulsed laser ablation has been identified as a suitable method to influence the cutting characteristics of superabrasive tool surfaces and generate tool topographies with defined abrasive elements.

Corresponding concepts of abrasive surfaces with controlled microgeometry made of solid diamond structures have been presented in [8,9]. This context demonstrates the beneficial properties of periodic structures and abrasive features with a positive clearance angle on the cutting conditions and the resulting workpiece surface finish. Similar conclusions can be drawn from the work of Transchel et al. [10–12] on the influence of the clearance angle on the cutting characteristics of brazed single diamond grains. Here, a significant reduction of the specific cutting force is achieved for diamond grains with a positive clearance angle.

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Commonly used electroplated or brazed diamond rotary dressing tools exhibit a stochastic surface characteristic regarding grain distribution, shape and the orientation of the individual abrasive elements. The former can be addressed by placing the grains in defined patterns on the tool body as reported in [13]. To some extent, the latter can be improved by sorting the applied diamond abrasives with respect to shape and size. However, essential geometric properties of the cutting edge such as rake and clearance angle cannot be influenced by any of these methods. In this regard, the laser ablation process enables new possibilities for generating diamond tool surfaces with enhanced functionality.

3. Objectives and experimental condition

3.1. Laser touch-dressing condition

The laser touch-dressing setup consists of an ultrashort pulsed solid-state laser system, which produces laser pulses at a wavelength of 1064 nm with a pulse width of $\tau_P = 10$ ps and a pulse frequency between 50 kHz and 8.2 MHz. The laser source is chosen to avoid thermal damage to the abrasive grain, as reported by Dold et al. [6]. The beam is guided by several mirrors, through retardation plates to ensure circular polarisation and a variable telescope to adjust the beam diameter. Finally, the beam is deflected through a two-dimensional scanning system and focussed by an f-theta lens with a focal length of 163 mm, resulting in a spot diameter of 35 μm. The scanning system is mounted on a linear Z-stage to align the focal plane with the tool surface level. The tool is clamped in a rotation stage on a high-precision XY-table for accurate radial infeed adjustments. A joint CNC system controls the four stages and the scanhead, allowing synchronised motions of the optical and the mechanical axes.

The laser touch-dressing process (Fig. 1) is performed by a tangential, linear scanning motion parallel to the tool's rotational axis. A continuous tool rotation counter to the beam direction is superimposed to generate a circumferential infeed for each scan. The uninterrupted motion ensures equal processing conditions for all stochastically distributed abrasive grains. The processing parameters (Table 1) are optimised to cut the abrasive grain and result in a v-shaped cutting kerf. Consequently, the processed grains exhibit positive clearance angles for a cutting operation in the direction opposite to the laser process.

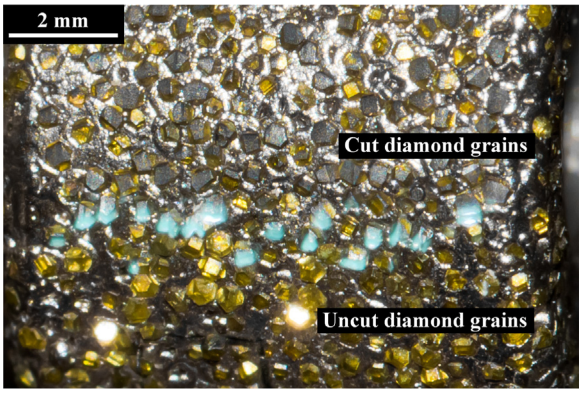

Fig. 1. Laser touch-dressing process. Plasma plumes are a visible effect of laser–diamond interactions and mark the boundary between the processed and unprocessed region.

Table 1
Specifications of tools and laser process.

Laser touch-dressing parameters		Tool specifications	
Pulse frequency	100 kHz	Tool diameter	12 mm
Average power	10 W	Tool width	8 mm
Pulse overlap	80%	Diamond grain	SDB 1125
Rotary infeed	250 nm/scan	Grain size	D426

3.2. Tool testing condition

Comparative experiments are carried out to evaluate the performance of the laser touch-dressed diamond tools. Vitrified bond corundum samples (A80G8V0057) are machined to simulate a grinding tool dressing process. Conventionally touch-dressed tools serve as reference. The laser touch-dressing process is applied in both rotation directions to compare positive and negative clearance angles. The setup for the tool tests (Fig. 2) is based on the work of Walter et al. [7], implemented on a modified Micron HSM 400U, five-axis machining centre equipped with a high-speed grinding spindle (Fisher MFM-10120/11). A customised nozzle applies Blasogrind HC5 oil as cooling lubricant and ensures repeatable processing conditions. The samples are mounted on a Kistler Minidyn Type 9256C1 platform to measure process forces. After an initial settling phase (3000 mm^3/mm), force measurements are conducted during a variation of the machining parameters (Table 2). To determine the long-term performance of the tool, further force measurements are conducted at regular intervals throughout the lifetime of the tools (70,000 mm^3/mm). The influence of the coolant flow on the force measurement is compensated.

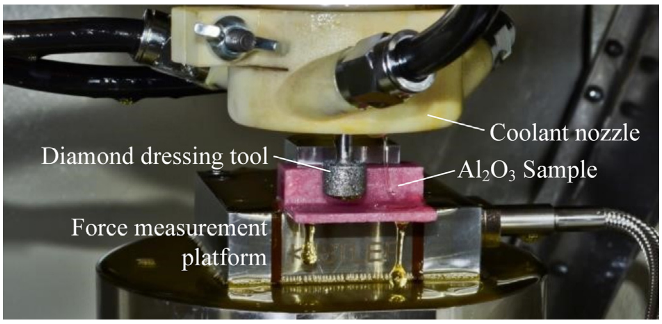

Fig. 2. Experimental setup used to test touch-dressed diamond tools.

Table 2
Machining parameters for tool evaluation.

Parameter	Dressing test	Long-term test
Feed rate [mm/min]	1500–9000	3000
Infeed [mm]	0.5–3	1
Width of cut [mm]	5	5

3.3. Abrasive surface measurement and analysis

3D-surface measurements around the circumference of the diamond tools, over a width of 1.4 mm, are performed after each force measurement with an Alicona Infinite Focus microscope. A cylinder is fitted into the measurement data by a least-squares algorithm to compensate for clamping deviations. Other than the removal of measurements artefacts, no further filtering is applied. Finally, the coordinate system is transformed to unroll the cylinder surface, enabling further analyses with a reference plane (Fig. 3). To analyse the clearance angles on the abrasive layer, the diamond grains in the measurement area are detected by a relative height

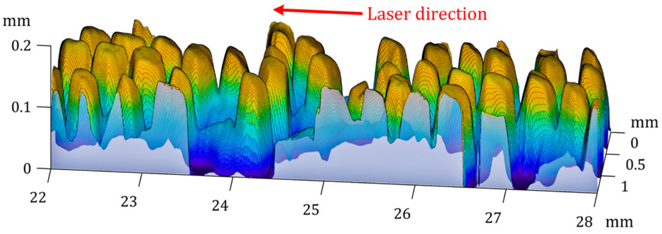

Fig. 3. Unrolled abrasive surface measurement data of a laser touch-dressed diamond tool with positive clearance angle.