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Laser Touch Dressing Of Electroplated CBN Grinding Tools

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Abstract

In this paper, an alternative process for dressing electroplated cBN grinding wheels using an ultrashort pulsed laser is presented. Other than abrasive grains dressed conventionally, laser touch dressed cBN grains exhibit cutting edges that have partially defined geometric elements with a positive clearance angle. Grinding experiments, including long-term tests, are performed on hardened steel, for a comparative study on the performances of laser dressed and conventionally dressed tools. While the processing forces are slightly higher for the laser touch dressed tools, the roughness of the ground surface is improved.

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Keywords: cBN; Laser; Dressing; Grinding

1. Introduction

Single layer electroplated cBN grinding wheels are increasingly put to use by reason of their high wear resistance, grit protrusion and large chip accommodation volume [1]. Due to uneven grain shapes and protrusion, electroplated wheels have a high surface roughness, which is detrimental to the surface quality and precision of the workpiece. The roughness of the tool can be improved by removing the tips of over-protruding grains in a touch dressing process [2], [3].

In this work, a laser touch dressing (LTD) process for single layer cBN grinding wheels, producing a clearance angle on the cut grains is presented. The surface characteristics and grinding performances of the tools are analyzed.

2. State of research

Nowadays, dressing processes encompass not only mechanical processes but also thermal, chemical or a combination of the aforementioned [4]. Laser has been increasingly used for the preparation of superabrasive (cBN or diamond) grinding wheels and especially for sharpening, since Westkämper [5] first reported on the dressing of a grinding wheel by laser. It has been shown that by creatively using short and ultra-short pulsed lasers, ordered structures ablated in superabrasive material influence the grinding characteristics. Walter et al. [6] studied the influence on the grinding performance and tool wear of various micro patterns generated by laser ablation, on the surface of hybrid bonded CBN grinding pins. Butler Smith et al. [7], [8] presented a laser ablation process to create abrasive structures with defined cutting geometries in thick-film CVD diamond. These structures proved to outperform conventional diamond electroplated abrasive elements, when grinding a Ti-6Al-4V alloy, resulting in a better surface finish of the workpiece.

The positive influence of a clearance angle on the cutting efficiency of abrasive grains [9] can be exploited by the laser machining of the abrasive grains on electroplated grinding tools. Dold [10] detailed a sequential laser process where the electroplated diamond grinding wheel is first dressed to the...
desired grain protrusion, before clearance and rake faces are generated on the diamond grains. The dressing forces of such wheels were found to be significantly lower compared to conventional tools. Warhanek et al. [11] demonstrated that the LTD process itself induces positive clearance on D 426 diamond grains which leads to an important reduction of processing forces compared to conventionally dressed tools when grinding vitrified corundum samples. In this paper the authors investigate the application of the aforementioned LTD process on CBN wheels for grinding hardened steel.

3. Experimental setup

3.1. Laser touch dressing

The LTD process is applied to single layer electroplated cBN grinding wheels. The tools’ specifications are listed in Table 1. For the LTD of the grinding wheels, a modified Laser Line from EWAG AG is used. The Laser Line is a compact, high-precision machine tool with an 8- axes kinematic, as illustrated in Figure 1. A solid state ultrashort pulsed laser with a pulse width \( \tau_p < 12 \text{ ps} \), a central wavelength \( \lambda = 1064 \text{ nm} \), a maximum output power of 35 W and a frequency range from 200 kHz to 8.2 MHz is used as beam source. Retardation plates placed in the laser path ensure a circular polarization. A focus shifting unit expands the raw beam before its entry into the scanner and can be used for shifting the position of the focal point along the W- axis. The scanner enables the deflection of the laser beam with a speed of up to 2000 mm/s in the working plane along the U- and V- axes aligned parallel to the X- and Y- axes. An F-Theta lens of focal length 163 mm focusses the beam to a focal spot of 28 \( \mu \text{m} \).

The workpiece is positioned via 4 mechanical axes (X’, Z’, C’, B’), while the Y- axis positions the scanner and is used for the radial infeed during the touch dressing process. For the LTD process, the tool is clamped on the C- axis, which is positioned parallel to the X- axis of the machine. The laser beam is deflected by the scanner in a repetitive linear motion parallel to the axis of the grinding tool. The scanner, and thus the hatch, is positioned along the Y- axis to touch the grinding tool tangentially to a set infeed. By a complete rotation of the C- axis in counter direction, the whole circumference of the tool is laser touch-dressed, ensuring that all grains are cut. The LTD parameters are summed up in Table 1. In this setup, the laser touch dressing process is completed in 22 seconds.

Table 1: specification of the grinding wheels and laser dressing parameters

<table>
<thead>
<tr>
<th>Grinding wheel specifications</th>
<th>LTD parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheel diameter</td>
<td>Average power</td>
</tr>
<tr>
<td>12.25 mm</td>
<td>29.4 W</td>
</tr>
<tr>
<td>Wheel width</td>
<td>Pulse frequency</td>
</tr>
<tr>
<td>10 mm</td>
<td>300 kHz</td>
</tr>
<tr>
<td>Grain type</td>
<td>Scanning speed</td>
</tr>
<tr>
<td>ABN 300</td>
<td>2000 mm/s</td>
</tr>
<tr>
<td>Grit size</td>
<td>Rotation speed</td>
</tr>
<tr>
<td>D 251</td>
<td>1000 (^{\circ})/min</td>
</tr>
</tbody>
</table>

3.2. Grinding experiments

The LTD tools are compared to conventionally dressed tools in a series of up-cut surface grinding experiments on hardened steel type 100Cr6 with a hardness of 60±1 HRC. The conventional dressing of the tools is done by Reishauer AG using their state of the art production process. Based on the setup used in [12], the grinding experiments are done on a modified Mikron HSM 400U five axes milling machine with a high-speed Fischer MFM-10120/11 spindle. Grinding oil, Blasogrind HC 5, at a flow rate of approximatively 50 l/min is used as coolant. Two sets of experiments are performed. The processing forces are compared for a variation of grinding parameters. This variation is done after machining a volume of 500 mm³/mm. The long-term behavior of the tool is studied by measurements at regular intervals throughout the lifetime of the tool, up to 5000 mm³/mm. The machining parameters are listed in Table 2.

Table 2: Machining parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Variation tests</th>
<th>Long term tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed rate, ( v_f ) [mm/min]</td>
<td>[1000-4000]</td>
<td>1000</td>
</tr>
<tr>
<td>Cutting speed [m/s]</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Depth of cut, ( a_e ) [mm]</td>
<td>[0.025-0.1]</td>
<td>0.05</td>
</tr>
<tr>
<td>Width of cut, ( a_t ) [mm]</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

3.3. Measurements and analysis

After dressing, the tools are analyzed using SEM and optical microscopy. Raman-spectroscopy measurements are carried out on three different cBN grains processed by laser to assess the thermal damage, using a WiTec CRM 200 confocal Raman microscope with x100 magnification and a CW laser source with \( \lambda = 532 \text{ nm} \) wavelength. Grinding forces are measured on the samples, mounted on a Kistler 9256C three-axis multi-component dynamometer. Each processing force is averaged over five measurements. The effect of coolant flow is compensated. During the long term experiments, at set intervals of material removal, processing forces, as well as roughness profiles of the workpiece are measured. The roughness is measured on an Alicona Infinite Focus 3D optical microscope. Each roughness value, filtered with a cutoff length of \( \lambda_c = 800 \text{ \mu m} \), is averaged over three measurements of 50 profiles each, taken along the width of cut. The abrasive covering of the tool is measured using an Alicona Infinite Focus equipped with a Real 3D rotation unit. The whole circumference of each tool is measured, over a
width of 1.4 mm, after each force measurement. An algorithm, as described in [11], is used to detect each abrasive grain. A plane is fitted on the top surface of the grain and the angle between the plane and the unrolled cylinder measured. This angle, dependent on the spindle rotation direction, represents the clearance or rake angle. In the following, a negative angle indicates a positive clearance angle when the tool rotates counterclockwise. In order to compare the peak bearing area of the tools along their lifetime, the material fraction, 5 \( \mu m \) below the highest measured point, is considered.

4. Results

Two tools prepared by LTD are compared to two conventionally dressed tools. The dressing processes lead to differences in the macroscopic shape of the tool, as well as to the shape of the grains, as shown in Figure 2.

During the LTD process, the grains are cut, leaving a flat top surface with defined edges. By conventional dressing, however, the grains are not cut but rather cracked, leaving a micro-fractured grain exhibiting a multitude of small, sharp edges [3]. Figure 3 shows the Raman spectra of a measurement performed on the top surface of a laser ablated cBN grain. The two peaks in intensity, 1057 cm\(^{-1}\) and 1306 cm\(^{-1}\), very much correspond to the peaks of cBN, as found in [13] (1054 cm\(^{-1}\) and 1306 cm\(^{-1}\)). The presence of a heat affected zone in form of hexagonal BN (hBN) can be ruled out since no peak at 1368 cm\(^{-1}\) is measured.

The results of the measurements, prior to grinding, of the clearance angle of over 200 grains on a LTD tool are compared to those on a conventionally dressed tool in Figure 3. The grains cut by laser exhibit an average clearance angle of 4.3°, with a standard deviation of 1.8°, while the conventionally dressed grains have a clearance angle of 0.5° with a standard deviation of 12.2°. The high standard deviation of the latter can be explained by the highly irregular shape of the grains and the difficulty to define a top surface on such grains. The effect of the clearance angle on laser-processed tools is clearly visible in Figure 4. The trends of the normal and tangential specific forces over the parameter variation are similar, although the tangential forces are up to four times smaller than the normal forces. The LTD tools exhibit processing forces strongly dependent on the rotation direction. The specific normal and tangential forces of the grinding experiments performed in CCW direction are an average of 62 % and 40 % lower respectively than those in the opposite rotation direction. The conventionally dressed tools do not present rotation direction dependent processing forces but exhibit similar results to the LTD tools used in negative rotation direction, 5 % higher specific normal force and 10 % lower specific tangential force. The differences in processing forces due to the rotation direction was already described in [11], although the LTD exhibited much lower processing forces than conventionally dressed tools.

The measurements of the specific normal and tangential grinding forces over the lifetime of the tools are plotted in Figure 5. Both normal and tangential forces follow a similar upward trend, with increasing material removal. Conventionally dressed tools exhibit forces lower than LTD tools, on average 16 % and 22 % for normal and tangential forces respectively. The peak bearing area is plotted, as a function of the specific material removed, in Figure 6. Both LTD and conventionally dressed tools exhibit a run-in phase where the bearing area diminishes quickly. After 500 mm\(^3\)/mm material removal, the bearing area of LTD stabilizes around 0.19. The bearing area of the conventional tool, however, follows a downward trend, diminishing 25 % over the next 4500 mm\(^3\)/mm. This downward trend suggests a

Figure 2: Top: Micrograph of the profile of a LTD tool (left) and conventionally dressed tool (right). Bottom: SEM micrograph of LTD grain (left) and conventionally dressed grain (right).

Figure 3: Left: Raman spectra measured on the top surface of a laser ablated grain. Right: Histogram of the clearance angle distribution on a laser and a conventional touch dressed tool.

Figure 4: specific normal (left) and tangential (right) processing forces of LTD (red) and conventionally dressed (blue) tools for the grinding of hardened steel with a variation of infeed \( \Delta z \) [mm] and feed rate \( v_f \) [mm/min]. The LTD tools were tested in the two rotation directions clockwise (light red) and counterclockwise (red). The error bars represent the average of each tool.

Figure 5: specific normal and tangential grinding forces of LTD (red) and conventionally dressed (blue) tools for the grinding of hardened steel with a variation of infeed \( \Delta z \) [mm] and feed rate \( v_f \) [mm/min]. The LTD tools were tested in the two rotation directions clockwise (light red) and counterclockwise (red). The error bars represent the average of each tool.

Figure 6: specific normal and tangential grinding forces of LTD (red) and conventionally dressed (blue) tools for the grinding of hardened steel with a variation of infeed \( \Delta z \) [mm] and feed rate \( v_f \) [mm/min]. The LTD tools were tested in the two rotation directions clockwise (light red) and counterclockwise (red). The error bars represent the average of each tool.
faster wear of the conventionally dressed CBN grains. The 59 % lower bearing area of conventional tools compared to LTD tools is in accordance with the microscopic analysis of the grains. It is assumed, that the expected reduction of processing forces due to the clearance angle on the grains, is compensated by the higher surface contact.

The surface roughness of the workpiece along the lifetime of the tool is shown in Figure 6. The LTD process leads to a better surface finish, on average 13 % lower Ra and 18 % lower Rz values, than the conventional process. The roughness diminishes with the increasing wear of the tools. The better surface finish on workpieces ground by LTD tools is to be attributed to the higher bearing area.

Figure 5: specific normal (left) and tangential (right) processing forces of LTD (red) and conventionally dressed (blue) tools when grinding hardened steel as a function of the specific volume removed. The error bars represent the average on each tool.

The better surface finish on workpieces ground by LTD tools is compensated by the higher surface contact.

Figure 6: Left: workpiece surface quality Ra (full line) and Rz (dotted lines) values as a function of the specific material removal. Right: Peak bearing area of tools as a function of the specific volume removed. The error bars represent the average on each tool.

5. Conclusion

In this work, an alternative process for touch dressing single layer electroplated cBN wheels is presented. The LTD process proves to be an efficient method for the preparation of cBN grinding tools. The LTD tools exhibit differences on the macro and microscopic level to conventionally dressed tools. The LTD process does not cause any significant thermal damaging of the cBN grain. Other than conventional dressing, the LTD process cuts through the grains generating an average clearance angle of 4.3 °. Grinding experiments highlight the influence of the clearance angle on the grinding process. LTD tools exhibit a 60 % higher bearing area than conventionally processed tools. Hence, it is expected that the tool life of LTD tools is improved. The higher bearing area leads to a reduction of 13 % of the Ra value, on average, on the surfaces ground by LTD tools. Grinding forces however are 16-22 % lower with conventional tools.

Further experiments will be conducted to investigate differences in tool wear and the possibility of applying the LTD process to grinding wheels with more complex geometries and smaller grain size.

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