# TRUEING OF MICRO-GRINDING WHEELS BY DIAMOND TOOLS

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## INTRODUCTION

The micro-grinding process with diamond micro-grinding wheels and abrasive pencils enables a fast and high-quality fabrication of microstructures in various hard and brittle materials [1, 2, 3]. When using cubic boron nitride (CBN) as abrasive, even hardened steels can be machined by micro-grinding [1, 4, 5, 6]. Micro-grinding wheels are very suitable for the machining of straight and open structures, but usually they can only fabricate structures with rectangular geometries because of their restriction of profile. The usage of micro-grinding wheels with a special profile, as for example a V-profile, is uncommon. This is due to the fact that micro-grinding wheels with a special profile are difficult to manufacture. Furthermore, the renewing process after the profile has worn is difficult to accomplish. A new approach is the trueing of CBN micro-grinding wheels by diamond tools.

## APPROACH

The technology of trueing grinding wheels by rotating diamond tools is highly favoured and well-established in macroscopic grinding technology. Trueing by rotating diamond tools is a reproduced process. The profile of the diamond trueing tools is the negative geometry of the desired grinding wheel profile. By moving the rotating grinding wheel against the also rotating trueing tool, the profile is machined into the peripheral surface of the grinding wheel, because the diamonds of the trueing tool are much harder than the CBN grains and the bonding of the grinding wheel. An easy kinematic, high quality and short processing times make this technology very efficient. Furthermore, this technology allows a periodical renewing of the profile inside the grinding machine. The approach to develop micro-diamond tools in order to realize a trueing pro-cess for CBN micro-grinding wheels is just a consequence of the named technological advantages.

## EXPERIMENTAL AND ANALYSIS

Generally, the miniaturizing of approved macroscopic production technologies is not a simple step. The process parameters and the process conditions often have to be optimized according to the requirements of micro dimensions. The aim of this study was to determine all influences on the trueing process and the trueing result. Besides the process parameters, the influence of the specification of the CBN micro-grinding wheels was one of the focuses in this study. CBN micro-grinding wheels are available with different bonding materials. These bonding materials, synthetic resin, bronze and nickel, are characterized by their different mechanical properties. In conventional grinding technology, grinding wheels with metallic bonds are very difficult to true by a mechanical process. In micro-grinding technology especially wheels with metallic bonds are favourable for many applications. So the focus of the endeavours was to develop a technology to true those micro-grinding wheels with metallic bonds.

Another question which had to be answered was how strong the influence of the specification of the chosen micro-diamond tool on the trueing process and the trueing result is. In this study three diamond trueing tools with different specification were tested (figure 1). Two of those tools were miniaturized wheels made of steel with a V-groove of an angle of 90 degrees. Both tools are covered with a single layer of electro-plated diamonds (46 micron and 15 micron). The SEM pictures of the trueing tool with the diamond grains of 46 micron in diameter showed a closed surface. The projection of the diamond grains was large and inhomogeneous as well as the chip space. Compared to this tool the surface of the trueing tool with the diamond grains of 15 micron in diameter seemed to be quite smooth. The projection of the diamond grains was small and also inhomogeneous.
A complete different type of tool were specially developed CVD-diamond trueing tools. The technology of CVD-diamond coats enables to be free in the design of tools and the thin coat covers very precisely the form of the tool body. Furthermore, the rough surface structure of this special diamond coat enables the machining of hard materials. In contrast to electro-plated diamond tools this synthetic diamond coat is characterised by a high homogeneous crystal structure and grain projection [7].

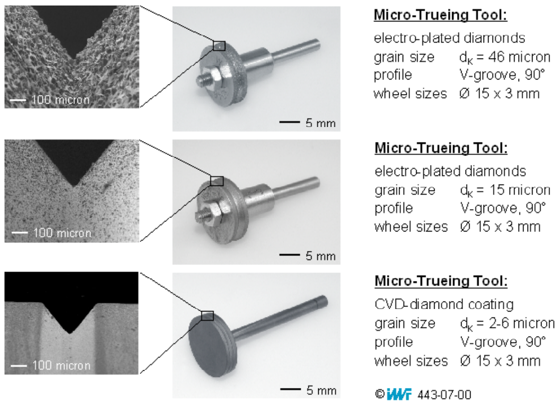


*FIGURE 1: Micro-diamond tools for trueing CBN micro-grinding wheels.*

For the experiments, a second spindle system for the trueing tools was integrated into the micro-grinding machine (figure 2). This spindle has a maximum rotation of 160,000 $min^{-1}$. Such high rotations were required because of the small diameter of the trueing tools (about 15 mm) and the high rim speed of the trueing tools which varied between 12 m/s and 72 m/s during the experiments. By this set-up, trueing and grinding experiments could be realized with high accuracy because no tool change was necessary.

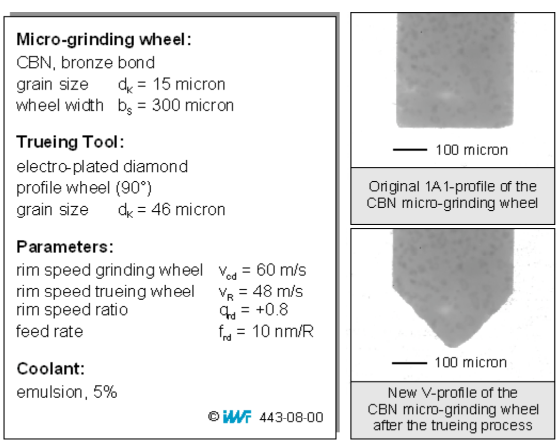


*FIGURE 2: Experimental set-up for trueing CBN micro-grinding wheels with diamond tools inside the precision tool machine.*

After each trueing process the machining result was controlled by grinding a groove into a small steel sheet with a thickness of just 40 micron with the trued CBN micro-grinding wheel. The geometry of this groove was analysed by optical measurement. The quality of the trueing result was characterised by the accuracy of the profile angle, the accuracy of the profile geometry and the radius of the micro-grinding wheel tip.

**EXPERIMENTAL RESULTS**

The first experiments were done with the CVD-diamond trueing tool. When using this trueing tool, all kind of CBN micro-grinding wheels could be trued. The quality of the created profile flanks was sufficient, and so was the performance of this tool. In contrast to the electro-plated trueing tools made of tool steel, the body of the CVD-diamond tool made of sintered carbide is very heavy. High rotation speeds (about more than 30,000 $min^{-1}$) could not be realized because of increasing dynamic forces and the incresing danger of a tool break. Another disadvantage is the difficult fabrication of the bodies for this kind of trueing tools because of the low machining ability of sintered carbide. During the fabrication of these tool bodies, the used grinding tools were affected by strong wear, so the realized profile of the trueing tool was not sufficient. This fact could be seen when using this CVD-diamond tool. The tip radius was about $r_s$ = 115 micron.

In order to obtain an optimized trueing tool, the CVD-diamond tools were further developed. Instead of heavy sintered carbide, light silicon was chosen for the fabrication of the tool body. With a newly designed prototype of a CVD-diamond trueing tool very high rotation speeds could be realized. Also the quality of the profile geometry could be increased and the tip radius was reduced down to 40 micron. With this new prototype tool, the experiments were continued and the trueing possibilities of all three kinds of micro-grinding wheel bonding material were tested. The grain size of the used micro-grinding wheels was about 15 micron and the width of the grinding wheels was 100 micron. In the experiments the rim speed of the micro-grinding wheels was $v_{sd}$ = 60 m/s and the rim speed of the diamond trueing tool was $v_{rd}$ = 48 m/s, so the rim speed ratio was $q_{rd}$ = +0.8. As coolant an emulsion of 5% was used. In order to obtain the machining efficiency of the CVD-diamond trueing tools and the trueing process, the feed rate was increased stepwise beginning from 1 nm per revolution.

The highest material removal rates were determined when trueing the micro-grinding wheel with the resin bond. The soft bonding material enabled feed rates up to $f_{rd}$ = 0.1 micron per revolution. At a feed rate of $f_{rd}$ = 0.2 micron per revolution the filigree micro-grinding wheel was damaged. Disruptions on the micro-grinding wheel were determined which point to high process forces and a too aggressive cutting process. Consequently, when trueing this kind of

CBN micro-grinding wheels the feed rate should be smaller than 0.1 micron per revolution. However, when grinding a control groove into the thin steel sheet no distinctive profile could be identified. After the trueing process a machined profile could be seen under microscope, but this profile of the 100 micron thick resin bonded micro-grinding wheel was very unstable, so that the newly created profile wears even under the low forces of the control grinding operation. Consequently, small CBN micro-grinding wheels made of a resin bond seemed not to be suitable for trueing and structuring. In contrast to this, micro-grinding wheels with metallic bonds seemed to be very expedient. When trueing these tools the quality of the profile was high, but the hardness of these bondings allowed only a slow trueing process with feed rates of just a few nanometers per revolution. Increasing the feed rate up to 10 nanometers per revolution or more, the thin micro-grinding wheels or the CVD-diamond trueing tool was damaged.

When using the electro-plated trueing tool with the large diamond grain size of 46 micron, micro-grinding wheels with a resin and a bronze bonding as well as a wheel width of 300 micron down to 100 micron could be trued well. The rough surface topography of this diamond trueing tool showed an efficient machining performance. High material removal rates and feed rates up to 0.1 micron per revolution could be realized. But the large diamond grains and the inhomogeneous grain projection created profile flanks with a low quality (figure 3). Furthermore, the possible minimal tip radius was also limited to $r_s$ = 35 micron because of the surface structure of this trueing tool. CBN micro-grinding wheels with a nickel bond could not be machined well with this diamond tool. Damages, as cracks and disruptions of material, could be noticed when machining this kind of micro-grinding wheels. The cutting process of this trueing tool with its large diamonds was too aggressive and inhomogeneous for this very hard metallic bonding material.

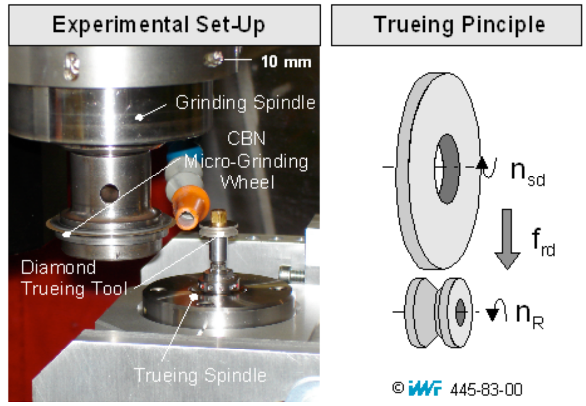


*FIGURE 3: Trueing of a CBN micro-grinding wheel by an electro-plated diamond trueing tool with grain size of 46 micron*

When using the electro-plated trueing tool with the smaller diamond grain size of only 15 micron CBN micro-grinding wheels with a resin bonding could be trued well. In contrast to that, the bronze bonding caused a closing of the small chip removal space. Furthermore, the inhomogeneous cutting process, because of the also inhomogeneous surface topography of this trueing tool, was again not suitable for the machining of CBN micro-grinding wheels with a hard nickel bond. Consequently, the application of this trueing tool specification was quite limited.

Generally, analysing the CBN micro-grinding wheels by SEM-pictures after all trueing processes, a quite smooth surface topography could be seen. As a consequence of that, the projection of the abrasive grains was extremly small, because the CBN grains were also cut as the soft bond material. This means that after the trueing process the CBN micro-grinding wheels are not really ready for an efficient machining process. Especially for those micro-grinding wheels with a metallic bonding a following sharpening process will be neccessary.

**SUMMARY AND OUTLOOK**

Micro-grinding with CBN tools is a very favourable method for microstructuring of hardened steels. Micro-grinding wheels with different profiles increase the structuring possibilities. Trueing of grinding wheels with rotating diamond tools is well known in conventional grinding technology. By the approach to miniaturize this special trueing technology, the fabrication of new profile geometries on CBN micro-grinding wheels as well as the renewing of those profiles could also be achieved now. The identified advantages of this new micro-technology are the easy and precise trueing process, which smoothly produces a symmetric profile on the filigree CBN micro-grinding wheels with a minimum width of just 100 micron. Furthermore, this technology is characterized by high precision and high efficiency because the micro-trueing device is directly integrated into the micro-grinding machine. That means that no accuracy failures occur because of a tool change of the micro-grinding wheel between grinding and trueing operation. As a consequence of that the run of the micro-grinding wheels is extremely good.

Different specifications for diamond trueing tools were tested in this study. The best results could be obtained when machining with a CVD-diamond trueing tool because of its homogeneous surface topography. Electro-plated diamond trueing tools sometimes enabled a fast trueing process, but the inhomogeneous projection of the diamond grains caused a lower machining quality. The used micro-grinding wheels with three different bonding materials could be machined with quite different effects. Best machinability was determined for resin bonded micro-grinding wheels, but this kind of tools were also subject to a strong wear, so that the application of these trued micro-grinding wheels was not very favourable. In contrast to that, metallic bonded micro-grinding wheels were difficult to machine. A bronze bond often caused a close of the chip space of the fine-grained diamond trueing tools. Nickel bonded micro-grinding wheels had to be trued very slowly because the hard material of these tools reacted quite brittle when machining too strong. However, these hard micro-grinding wheels showed the best trueing results and performance. Generally, all CBN micro-grinding wheels had an insufficient projection of the abrasive grains after the trueing process. Consequently, a sharpening operation will be neccessary after trueing these grinding tools.

Within further studies optimized CVD-diamond trueing tools made of silicon bodies will be tested. These tools are characterized by profiles with a very small radius and different angles. Furthermore, the fabrication of complex profiles onto the CBN micro-grinding wheels as well as the performance of trued CBN micro-grinding wheels will be the focus of further studies.

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