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Flexible mono- and multilayer micro grinding tools for ultra-high precision processing and micro machining

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Abstract
In this investigation, we report about the concept and the novel production process of mono- and multilayer micro grinding tools combining photolithography and joining technology. Main points of the investigation, in addition to the production process, are the achievable surface quality and the process reliability. The use and combination of analytical instruments, such as scanning electron microscopy with elemental analysis ensure the characterization of the defined properties.

Keywords: Precision engineering, ultra-high precision machining, micro grinding

1. Introduction

Functional surfaces of components made of ductile materials such as copper or high-alloy stainless steel, as well as brittle materials such as silicon, often demand the highest standards of surface quality, which can only be achieved by post-treatment steps. In the area of surface machining, a distinction is made in particular between ultra-precision and micromachining. Smooth surfaces with roughness values of Ra < 0.2 µm are processed using ultra-precision machining processes (e.g. polishing, honing, ion beam figuring). On the other hand, structured surfaces (Ra > 0.2 µm) are produced using micromachining techniques (e.g. micro-grinding, lasers). The functionalization can be achieved by targeted modification and activation as well as by coating and structuring of the surface [1, 2].
The current state of research shows increasing requirements to the performance and efficiency of high-alloy stainless steel components with high surface quality and functionalized surfaces. As part of this investigation, both requirements concerning the profile of face grinding (ultra-high precision processing) and peripheral grinding (micro grinding) are fulfilled by a single novel procedure. However, up until now there is no knowledge of the boundary conditions of the thin film technology for high quality machining of mono- and multilayer micro grinding tools. The manufacturing process will be considered to achieve the defined goal. As regards to the demands made on the micro grinding tools the properties are being evaluated. Subsequently, the grinding tools which are developed and manufactured for the use of micro-abrasive grinding are examined with regard to their behaviour in the use of ultra-precision- and micro machining.

2. Experimental procedures

This preparatory work includes the production of mono- and multilayer micro grinding tools (see Figure 1) as well as their application in face and peripheral grinding tests. Polyimide is used in order to integrate the abrasive grain permanently and deep into the basic body material of the grinding tool. This photoresist has a high thermal stability as well as a high mechanical strength and wear resistance [3]. Due to the use of polyimide as a base material, the bonding of the abrasives was already possible during tool generation. A mix of the abrasive in the polyimide was applied by spin-coating with a defined

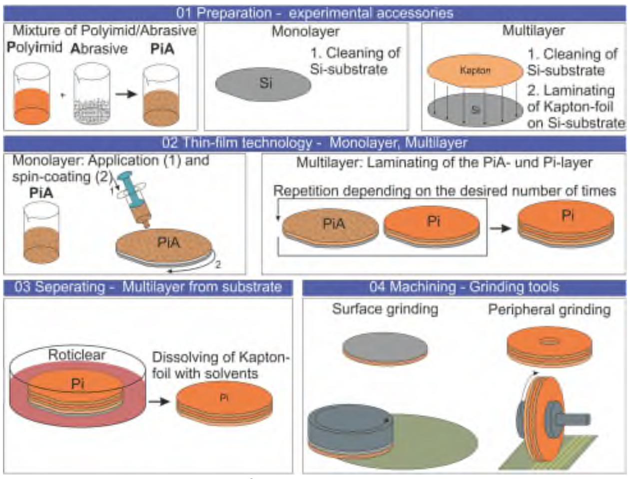

Figure 1 Production chain of mono- and multilayer grinding tools

layer thickness and the bond matrix was adjusted by thermal post-treatment. The topological properties were specifically influenced by the addition of F360 corundum (Al_2O_3) as abrasives. In order to demonstrate the potential of polyimide as a bonding matrix, the first tool prototypes were produced using thin-film technology. For this purpose, a homogeneous polyimide abrasive mixture of 40 ml of polyimide and 4 g of Al_2O_3 with an average grain size of 21.6 µm was produced.
Subsequently, a rotary coating of a glass wafer (Ø 100 mm) was applied as a carrier substrate with the produced mixture. Since the abrasive layer adheres to the substrate and the abrasive is permanently bonded, an exposure process and thermal treatment of the tool took place at 200 °C. The abrasive layer is then bonded to the substrate. In order to carry face grinding tests, a steel disc made of X20Cr13 was ground flat across the entire contact surface between workpiece and tool using the monolayer micro-grinding tool. The tool was clamped on a wafer holder and used according to the kinematics of a single disc lapping and polishing machine. The quality of the steel disc surface can be assessed by roughness measurements (Rmax, Rz and Ra).
The presented process for the monolayer micro abrasive tool was modified and a tool with several layers consisting of abrasives-containing layers and abrasives-free layers (supporting layers) was realized. This further development and modification enables the change from face grinding to external periph-

eral grinding process with a multilayer micro-grinding tool. In order to demonstrate the potential of this micro-grinding tool for the production of microstructures, first prototypes were produced at the IMPT and investigated at the IFW. The tool used in the preliminary examinations consisted of five layers. These are divided into three support and two abrasive layers. The preliminary investigations were carried out using an external peripheral grinding process on a steel workpiece X20Cr13. The abrasive layers consisted of a 60 µm thick Al_2O_3 layer in a polyimide bonding matrix. A thickness of 100 µm was chosen for the support layers. The total thickness of the tool, which was checked and confirmed metrological, was 320 ± 5 µm before use.

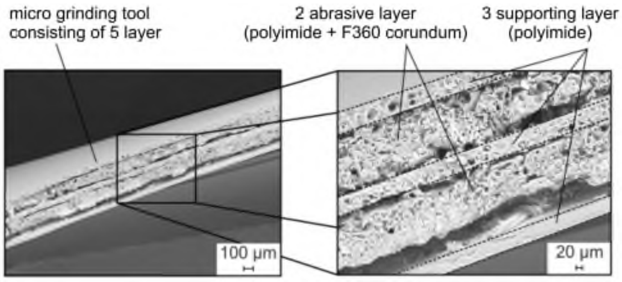

Figure 2 SEM image of a five-layer micro-grinding tool prototype

Figure 2 shows SEM images of the five-layer micro-grinding tool after use. The images show that the layer thicknesses do not correspond to their original values. This is due to the fact that the support layers have detached from the abrasive layer and were pressed towards the tool centre during the external peripheral grinding process. In the experimental preliminary investigations, the control variables cutting speed vc = 20 m/s and feed rate vf = 100 mm/min. The cutting depth was varied with ae = 20 µm and ae = 60 µm.

3. Results and discussion

The tool was used for this purpose 10 minutes in the first test and 150 minutes in the second test. The roughness values of the unmachined (before) and polished surface (after) were recorded (see Figure 3). The preliminary investigations show a significant change in the steel surface. The roughness parameters Rmax, Rz and Ra decrease with increasing processing time. The reproducibility of the results was confirmed by repetition of tests and measurements. The investigations show that the tool is principally suitable for machining high-alloyed stainless steel. However, the surface quality may be further reduced by optimizing the bonding material and reducing the amount of abrasives used.

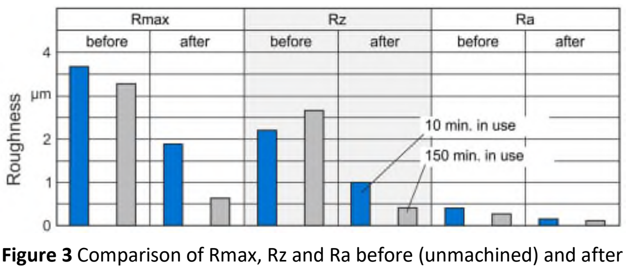

Figure 3 Comparison of Rmax, Rz and Ra before (unmachined) and after (machined, 10 min and 150 min)

Figure 4 shows the individual grinding paths represented by the ground grooves. The ground grooves reflect the negative of the micro-grinding tool. Material was only removed in areas where the abrasive layer of the grinding wheel had contact with the component. No material was removed between the two grinding grooves and on the outer surfaces by the support layer and the support layer was self-reset (straightened and conditioned). The results show that the accuracy decreases with larger cutting depths and that a maximal groove depth of 5 µm is achieved with an intervention depth of ae = 20 µm. The reason for these deviations lies in the deflection of the grinding tool due to excessive compressive forces and the resulting reduction in material removal. There is also a need to investigate the grinding and wear behaviour of tool profiles. When comparing the grinding result with the tool, it is striking that the width of the abrasive and support layers is not reflected in the dimensions of the grinding paths examined. This is due to the peeling layers whose pathways behave unstable in the process. The investigations show that the multilayer moulds are basically suitable, e.g. for the following applications high-alloyed stainless steels. For low cutting depths, the defined microstructures are clearly visible in the form of two parallel grooves (see Figure 4).

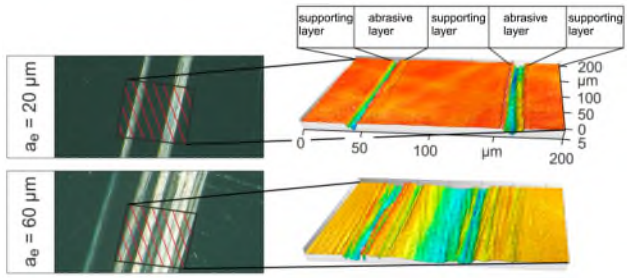

Figure 4 First microstructures using prototypes of the multilayer micro-grinding tool

4. Conclusion

The preparatory work at the IFW and the IMPT shows that two grinding wheel types can be produced with a new type of process for both requirement groups of face and peripheral grinding. The innovative manufacturing process of the new grinding wheel types features the advantage that time-consuming profiling processes in production and complex dressing processes during machining are obsolete with regard to the peripheral grinding tools used for micro-structuring. Expensive profiling and dressing tools are no longer required. There is also no need for laboratory-intensive conditioning processes when it comes to face grinding tools for ultra-precision machining. In addition, abrasive grains can be introduced in a targeted manner during the manufacturing process, so that appropriate structures can be produced. Thus far the knowledge of how mono- and multilayer micro-abrasive tools have to be designed for high-quality processing under the manufacturing conditions of thin-film technology is missing. The connections between the manufacturing process and the application behaviour of the newly manufactured grinding tools are unknown. Furthermore, the research demand is directed at the methods of thin-film production itself. The preparatory work shows the current challenges of layer bonding.

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