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MECHATRONIC SYSTEM FOR THE HYBDRID-MACHINING OF BRITTLE-HARD MATERIALS

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Abstract: *This paper deals with the development of an ultrasonic workpiece table for the machining of brittle-hard materials like glass, ceramics and carbide. Thereby the workpiece is moved with a frequency of about 20kHz and amplitudes of up to 15 microns. These vibrations support the main cutting process and enhance the supply of the coolant lubrication. With the implementation of the vibration measurement a closed-loop control was built.*
Key words: *ultrasonic, grinding, ceramics, glass*

1. INTRODUCTION

The optimazation of the functionality of products leads to the application of modern materials which comes along with new production requirements.

Brittle-hard materials like glass, ceramics or carbides are used for applications with high mechanical stresses and high mechanical or chemical abration. An overview of the physical characteristics of these materials is shown in the following figure.

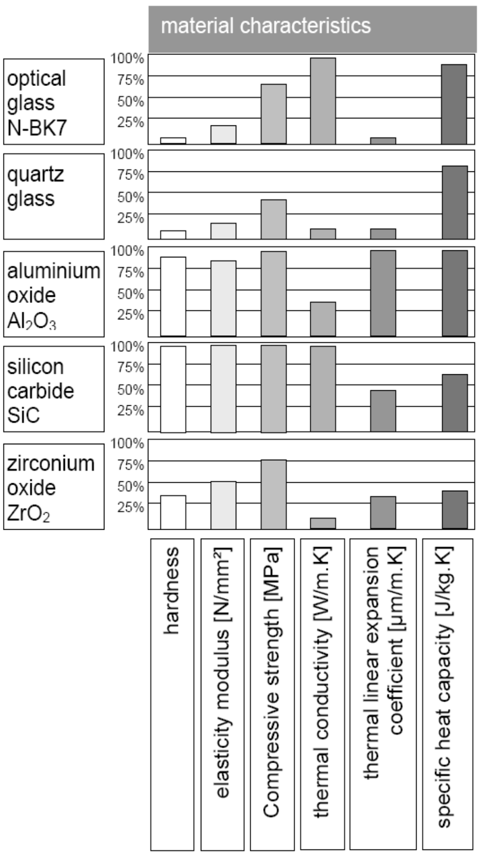

Fig. 1. Mechanical characteristics of brittle-hard materials

NC-grinding is the preferably used method in machining technology for these materials. Tools are available starting from small diameters, like mounted points or end mill shaped cutters, up to larger dimensions like cup wheel cutters. The grain size comprises dimensions from less than 10 microns up to more than 200 microns. For the machining of bridle-hard materials developments on the area of ultrasonic-supported machining have been made in past. Especially one producer of machine tools is known in the field of practical application.

2. OPERATING MODE OF ULTRASONIC

For ultrasonic-supported machining a rotating tool is used similar to the process of jig grinding (Spur, 1995; König, 2001; Klocke, 1999; Uhlmann, 1999;). The following figure shows mounted point with the tool holder and the housed actuating elements.

Fig. 2. Ultrasonic tool with measurement device

The tool is rotated by the main spindle and effects the main cutting motion. The material removal is done like in a standard grinding process. In the common machine solutions a subsidiary motion can be performed additionally to the main cutting motion. In order to achieve this subsidiary motion the tool is stimulated in the direction of the axis of rotation with high frequency and low amplitude vibrations (hybride machinig). For this purpose a piezoelectrical actuated resonator is used, which is typically implemented in the tool holder (Schinhaerl, 2004;).
The oscillation frequency is adjusted in a way that the tool is activated in an axial resonance frequency. This resonance frequency, determined by both the geometric shape of the tool and the tool mass, lays at approximately 20kHz. Due to the resonance effect a superelevation of the amplitude is done with resulting elevation values between about 1.0 microns to 3.5 microns. The resulting process interaction helps to perform machining applications on new materials, which are actually not machinable.

3. DESCRIPTION OF THE TECHNOLOCIAL ADVANTAGES

The activated tool modifies the cutting process through the subsidiary motion. On the one hand the main cutting process is supported directly by the vibration of the tool and on the other hand the supply of the coolant lubrication to the cutting edge and the material discharge from the cutting zone is alleviated. Especially the latter effects lead to a reduction of cutting- and feed forces in the order of about 10% to 25% for the machining of brittle-hard materials. Due to the lower thermal stress of tools an improved lifetime can be achieved.

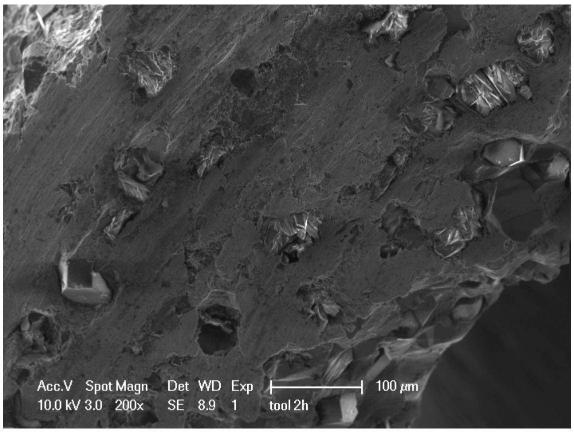

Fig. 3. Surface of an mounted point with grainsize ~ 50 microns

4. GOAL OF THE DEVELOPMENT

The aim of the work at the Institute for Production Engineering and Laser Technology was to develop a device for ultrasonic-supported machining which seeks to meet the following requirements:

- Mounting of the vibrating device on conventional machine tools as mechatronic clamping device
- Direct mounting of workpieces on the vibrating device
- uniaxial excitation of the workpiece in a closed-loop system for a guided setup of frequency and amplitude

5. REALIZED ASSEMBLY

To achieve this goals the following device was developed (see Fig.4). In a brass housing a vibratory device is installed. The vibrating device consists of a double array of piezoelectric actuators. These are preloaded by a single screw nut. The drive side is connected via a cylindrical body with the workpiece holder. Due to the extension of the piezoelectric ceramics by the supply of electric current the mechanical structure implemented in the housing lenghtens in axial direction. Through the induced oscillation, the sonotrode is brought to resonance. Especially since there is almost a mass equivalence between the driving side and the workpiece side including the workpiece, an axial longitudinal oscillation can be achieved. The vibrating system is connected to the housing by a membrane located at the height of the vibration node (see Fig.4). For processing in a closed-loop system strain gages are applied.

The mechatronic workpiece fixture has been designed by the use of finite element methods to achieve significantly larger amplitudes compared to the state of the art.

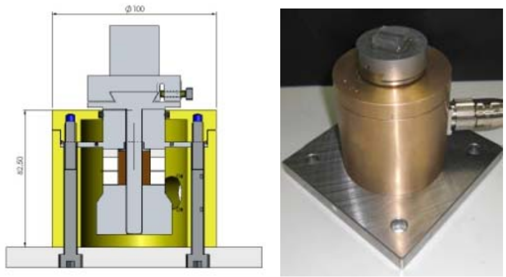
Fig. 4. Ultrasonic workpiece table

For the excitation of the sonotrode two piezo-ceramic rings (38x20x8mm Ag, measured capacity 1nF per ring) were implemented. On the microprocessor-based sine wave generator with a serial interface to a master PC, both the frequency and the amplitude of the output signal can be adjusted. The set parameters are sent to an amplifier, which is supplying the piezoelectric rings with up to $1000V_{ss}$.

To determine the oscillation frequency and amplitude, a strain-gauge bridge-amplifier with adjustable phase angle of the output signal was constructed. A corresponding software based on LabView handles the entire control and regulation of the system (Pitschke, 2005; Conradt, 2006;). The limits in the use of this mechatronic workpiece fixture derive from the weight limitation of the workpiece and come along with the frequencies, which have to be selected to obtain a resonance vibration.

6. ACHIEVED RESULTS

For the metrological control of the resulting vibration and the calibration of the strain gages, an eddy-current measuring system for contactless measurement was used. The metrological analysis of the vibrating device demonstrated that in the respective resonance frequencies amplitudes of up to 15 microns can be achieved.

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