INFLUENCES ON SURFACE AND SUBSURFACE DURING ULTRASONIC ASSISTED GRINDING OF ADVANCED CERAMICS

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Introduction

In ultrasonic assisted grinding, the kinematics of the conventional grinding process are superimposed with a high-frequency longitudinal motion of the tool or the workpiece. Like in ultrasonic lapping, the excitation is realized by an external voltage generator and a sonic transducer that works on the piezoelectric principle. The ultrasonic motion is characterized by a frequency of about 18-25 kHz and an amplitude of about 4 μm which, however, can be increased by up to 50 μm with the help of sonotrodes. Ultrasonic assisted grinding has a high potential for an economical machining of hard and brittle materials like glass or ceramics, particularly in the generation of complex contours. Adjusting the kinematic parameters also permits a purposeful micro-structuring of the workpiece surface and serves to avoid directional machining patterns normally observed in grinding.

Current investigations have shown that ultrasonic assistance leads to a fundamental change in the surface formation and wear mechanisms as compared to conventional grinding [Uhl98]. The thermal load is distinctly reduced, whereas the mechanical load increase due to the pulse-like grit engagement. It was noticed that this could reduce the grinding forces by at least 40%. At the same time, a very high surface quality and a low, almost stationary grinding wheel wear could be achieved.

The impact of ultrasonics on subsurface properties, however, is yet to be reported in the literature. To determine the subsurface damages caused by ultrasonics, experimental investigations on the bending strengths due to machining, residual stresses, and surface qualities, as well as grinding temperatures were carried out. This paper will show that ultrasonics do not cause a deterioration of the subsurface properties in comparison with conventional methods. Moreover, the generated compressive residual stresses are more favorable than during grinding without ultrasonic assistance.

Procedure variants and functional principle

In order to realize the different kinematics variants which show different positions of the active partners, tool and workpiece, in relation to each other, the ultrasonic vibration can be induced into the contact zone by the tool as well as by the workpiece. With reference to DIN 8589 T 11 the in **Figure 1** displayed kinematic modifications take place.

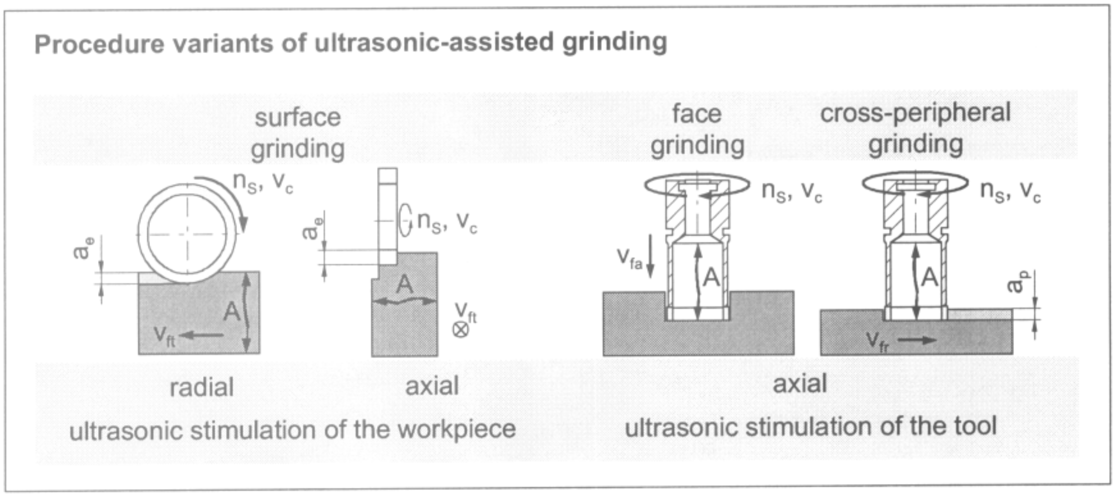

Figure 1: Procedure variants of ultrasonic assisted grinding [SpuH95]

The introduction of an additional motion component into the interacting zone leads to a change in the motional relations of diamond grit and workpiece surface. In **Figure 2** the changed kinematic conditions are displayed using surface grinding as an example. The introduction of an additional motion component in the interacting zone leads to a change in the motion ratios between the abrasive grain and the material surface.

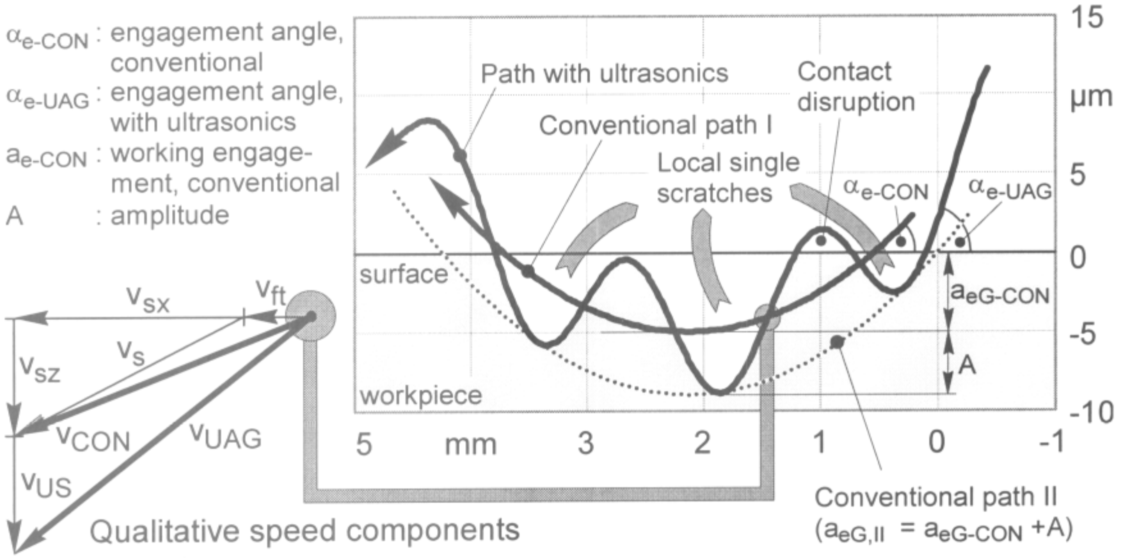

Figure 2: **Calculated motion path of a cutting edge with radial ultrasonic stimulation of the workpiece in comparison with the conventional motion path**

As a result of the ultrasonic motion there is a constant change of direction of the active speed and contact conditions, consequently the surface formation as well as the wear mechanisms change.

If the feed speed is ignored, the path of the grits during grinding without ultrasonic describes the segment of a circle. The grits penetrate into the material in relation to the conventional working engagement $a_{eG\text{-}CON}$ with a constant wheel speed v_s and a defined conventional angle of engagement $\alpha_{e\text{-}CON}$. The maximum depth of cut is reached at the lowest point of the curve. After leaving the surface, the grits have marked a trace of the length $l_{Rt\text{-}CON}$ [Uhl98].

Additional kinematic measures by means of longitudinal workpiece vibrations in radial direction cause significant deviations from the circuit described before. Depending on how many workpiece vibrations are realized per contact phase, a number of single scratches locally strung together with different depths and lengths of cut emerge instead of a circular engagement. The maximum depth of cut increases by the value of the amplitude A at nominally equal working engagements. Complete contact disruptions occur between the local single scratches. Due to the additional speed component in radial direction v_{US}, the grits hits the surface hereby at a larger angle of engagement with higher active speed v_{UAG}. Each local single scratch is characterized by distinctly shorter contact times and single lengths of scratch, as well as higher engagement depths [Uhl98].

Besides the described radial stimulation of an active partner, the ultrasonic vibration can also be generated axially to the tool axis during surface grinding. A complete disruption of contact between the tool and the workpiece, instead harmonious machining patterns are formed on the workpiece surface. Because of the kinematic conditions with a constant change of active direction, different contact paths are superimposed and the process forces are reduced as during radial ultrasonic stimulation. On the machined workpiece surface, homogenous surfaces with an improved tribological behavior are formed [Zap98]. **Figure 3** demonstrates the influence of the ultrasonic vibration on the structure of the machined surfaces. In the left part of Figure 3, locally lined up single scratches are noticeable, which derive from the radial ultrasonic stimulation. The machining traces shown in the right part of Figure 3 are not disrupted, because the vibratory movement is superimposed here in axial direction.

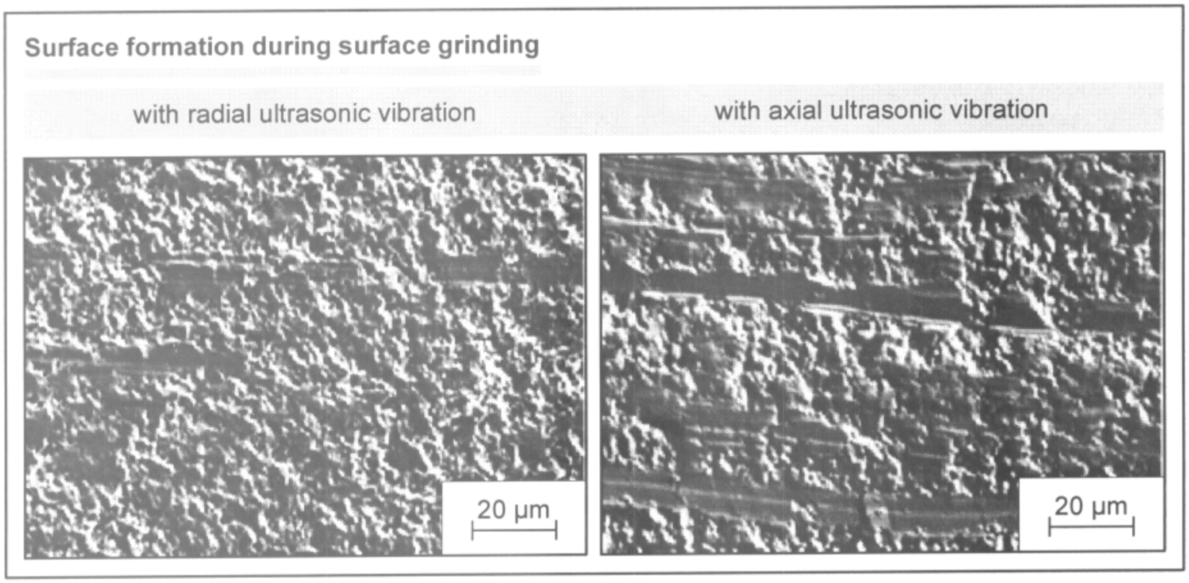

Figure 3: Surface formation during surface grinding with radial and axial ultrasonic vibration as shown in the example of Al_2O_3

Depending on the vibration frequency and the peripheral speed undulating machining patterns occur during each individual single contact, of which the layout is different than the one during conventional grinding.

Influence of ultrasonics on surface and sub-surface.

Increased mechanical load and reduced thermal load on both partners are a result of ultrasonic assistance. Due to a change of active principles during surface formation, a change of the wear behavior on the grinding tool occurs. Grit flattening on the diamonds are increasingly replaced by micro-splinterings. Contrary to conventional grinding, sharp single cutting edges are hereby generated. In the course of the process time, the amount of single cutting edges increases compared to conventional grinding. Hence the degressive increase of the process forces is significantly reduced and transmitted to a quasi-stationary force development. The respective wear mechanisms balance each other out, in a way that altogether an almost unchanged radial wear can be noted, compared to the conventional process.

Aside from the change in force behavior, a significant reduction of the grinding temperatures occurs in the contact zone. Due to the disruption of the tool-workpiece contact, the contact times of the individual diamond grits are shortened and thus the frictional effects between the active partners are reduced. Moreover, the introduction of the cooling lubricant and the transport of the material removal is improved. From the measurement of the marches of temperature using thermal elements in the sub-surface of the workpiece, a decrease in temperature of up to 30 % has been established during ultrasonic grinding. During the machining of silicon carbide for example, temperatures in the sub-surface decrease from 90 °C to 70 °C (**Figure 4**). The determined diminution of the sub-surface temperatures of the workpiece leads to the conclusion that the temperatures influencing the diamond grits also decrease.

In the course of further investigations at the IWF Berlin, the sub-surface characteristics after machining were compared. For the characterization, bending strengths and residual stress conditions are usually established. Additionally, the tool topography and the surface quality give information about fissures and strains that determine damages in the sub-surface area. The determination of the quality of the machining results is carried out by comparing the results with those of plan-parallel lapped workpieces.

Here it is important to clarify whether or not the ultrasonic superposition leads to intolerable damages on the component.

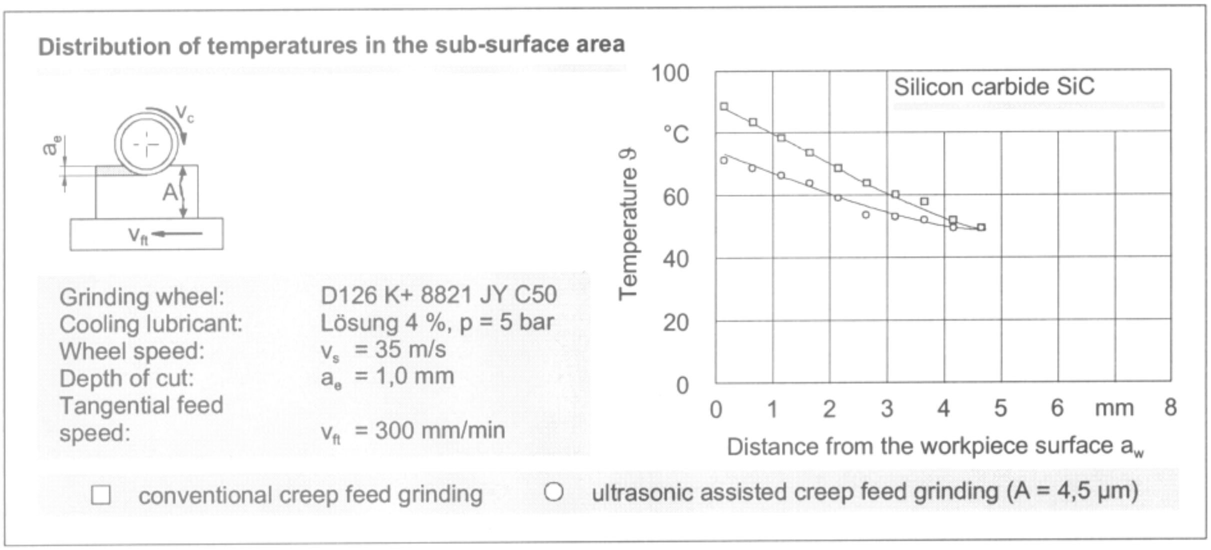

Figure 4: **Distribution of temperatures in the sub-surface area of the workpiece during creep feed grinding of SiC with and without ultrasonic assistance**

The bending strengths of ultrasonic assisted ground samples are lower than those measured during conventional grinding but higher than during lapping. It was also noted that greater compressive residual stresses in the sub-surface are a result of the ultrasonic assistance. During subjective observation of the surface structures with an SEM, slightly higher percentages of brittle fracture due to ultrasonics could be observed, which did not bring about a significant deterioration of the surface quality. For surface grinding with radial ultrasonic stimulation and cross-peripheral grinding with axial ultrasonic stimulation, critical sub-surface damages that hamper the application behavior can be excluded.

Conclusion

The superposition of grinding with an ultrasonic vibration causes a change of the process behavior. So far it had not been clarified to what extent the changes effect the process characteristics and the work result. Hence the influence of the superposition of the vibrations on the process forces and process temperatures as well as on the surface quality and the sub-surface characteristics were investigated. Distinctly reduced machining forces were measured. The thermal stresses decrease while the pulse-like alternating stress lead to higher mechanical load. The surface quality and the radial wear remain almost unchanged despite the significant changes of the surface formation and wear mechanisms. After the bending strength and residual stress investigations, critical sub-surface damages can be excluded.

References

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