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HYBRID MACHINING OF SIC

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Abstract: *Due to their physical properties, ceramic materials are becoming more widely used as construction materials. In particular, SiC, having a high oxidation resistance, good thermal conductivity and high hardness make it a very advantageous material. In the hybrid process of ultrasonic-assisted grinding, there are single and multi-axis movements between the tool and work-piece in addition to the main rotational movement of the cutting tools. These additional relative movements along with the use of ultrasonics open the door for opportunities in the optimization and extension of tool life in the machining of SiC.*
Keywords: *hybrid machining, SiC, ultrasonic assisted grinding, diamond tools*

1. INTRODUCTION

Advanced ceramics are divided based on their material characterization as oxides, non-oxides and silicate ceramics. Due to the shared covalent bond and narrow atomic distances between molecules, these materials are characterized by high strength, hardness with limited ductility, and a high chemical and thermal stability. These material properties also determine the material's machining characteristics as well. The workability of ceramics is due to its low fracture toughness as well as being classified differently than metallic materials.

Common SiC ceramics are sintered from SiC Micro-powder at temperatures from 2000° C to 2200° C under inert gas pressure (SSIC), or are being used in reaction-silicon infiltrated silicon carbide (SiSiC). The latter consists of about 70% silicon and about 30% carbon, and is composed of approximately 85-94% SiC and correspondingly from 6-15% metallic silicon. The pore space is filled with metallic silicon, making the residual porosity of SiSiC negligible.

2. HYBRID MACHINING

Hybrid processing methods combine two or more modes of action in a single process. For processing of ceramic materials, there are known methods which correspond to the conventional grinding process with ultrasonic vibration added to the tool or work-piece. When machining SiC ceramics, diamond-cutters (wheels) with diameters ranging from 1mm to 20mm are typically used. The tools are often designed as a hollow drill and placed in the tool holder either with a cone adaptor, a vendor-specific solution with facing systems, or placed directly onto the spindle. The abrasive layer is applied at the shaft and can be recycled several times. Through ultrasonic stimulation tools achieve a longitudinal oscillation preferably at their resonance frequency. The shape of the tool is important for the characteristics of frequency transmission.

3. EFFECT OF ULTRASONIC VIBRATION

The interference due to the superposition of the individual particles produces a variable chipping width. The ductile region in the process of machining brittle-hard materials is bordered by the critical chip thickness hcu,crit. Bifano describes a calculation model (1) for the continuous cutting surface, taking into account a factor ψ of surface injury, the fracture toughness K_c, the Vickers hardness H and Young's modulus E.

$$h_{cu,krit} = \psi \cdot \left(\frac{E}{H}\right) \cdot \left(\frac{K}{H}\right)^2 \qquad (1)$$

For the machining of hard-brittle materials $\psi = 0.15$ is used. For SiSiC the critical chip thickness $h_{cu,crit}$ is determined to be about 35nm. Due to the properties of silicon carbide, having a high hardness and low fracture toughness K_{Ic}, the material tends to be increasingly susceptible to brittle fracture as material removal proceeds.

4. MACHINING OF SISIC

The high frequency vibration of ultrasonic stimulation through its nearly point-like introduction has a significant influence on material removal behavior. The machining of slots with diamond cutters and full coverage, results in a larger contact area between the work-piece and tool. To illuminate the effect of ultrasonic stimulation in a real cutting process, experiments were conducted at a Gildemeister ULTRASONIC 75. There is a mechanical coupling that occurs to the work-piece when the tool becomes in contact.

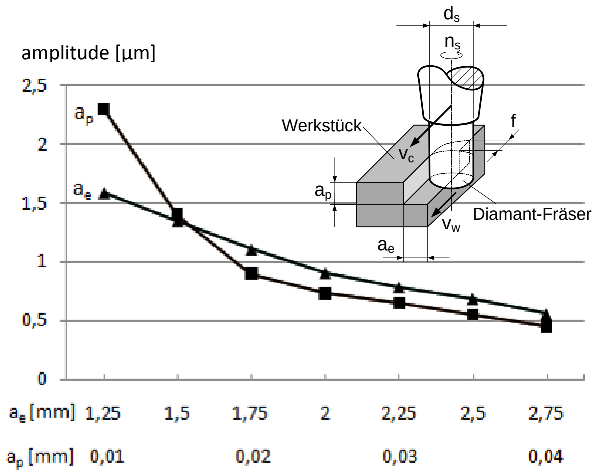

Fig 1. Damping attenuation of the amplitude as a function of cutting parameters

This behavior could be described by the stiffness of the contact K_E and the resulting damping D_E; i.e. $D_E = f(Q_W)$ can be considered as a function of the contact parameters. The contact damping can lead to the eradication of resonance effects on the tool. Upon contact, the amplitude of the ultrasonic vibration is reduced to approximately the net stroke of the piezo actuator. This reduced amplitude is not due directly to mechanical coupling of forces but rather the passive displacement of the system that occurs when the piezo is activated.

To investigate the influence of ultrasonics on the life of the tool, cutting tests were carried out. Test pieces were fixed by using a vacuum clamping method. The tools used had a diameter of 2mm, 2.5mm, 4mm and 5.5 mm, and grain sizes of D91 and D107 at a concentration of C200. The cutting speed is limited by the machine-specific maximum speed possible with ultrasonic use. For a diameter of 5.5 mm, a max cutting speed vc = 138m/min is possible. According to the data in the diamond tool recommendation section, a minimum work-piece speed of vw = 0.4 m / is chosen. This corresponds to a speed ratio of q = 345. With a contact width of a_e = 5.5 mm, i.e. full coverage, the average chip thickness results to be h_m = 0.49 microns.

$$h_m = \frac{\lambda_{Ke}}{q} \cdot \sqrt{\frac{a_e}{D_s}} \qquad (2)$$

The input feed was chosen with a_p = 0.02 mm. The processing took place using a non-water processing oil with a viscosity ν = 7.9 mm²/s.

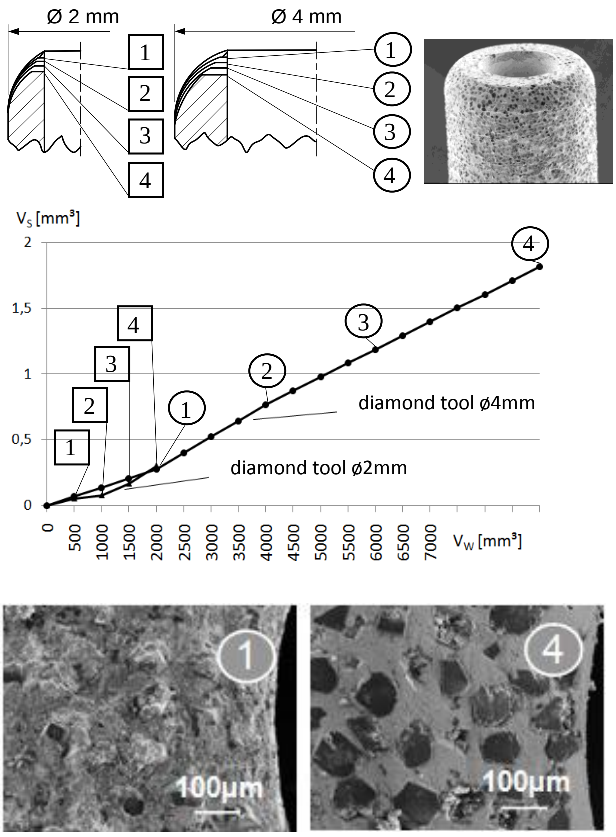

Fig. 2. SiSiC-cutting tests with diamond tolls and ultrasonic vibration

Fig 2 shows the wear of a tool with a diameter of 2 mm and 4 mm respectively, after four cycles of use. There is a reduction of tool length as well as a flattening that occurs. As a service life criterion, the increase in feed force was used. The graph shows the tool wear as a function of the machined volume (G-factor). The experiments show that, the use of ultrasonic vibration caused a significant increase in tool life. Without ultrasonic excitation, tools showed a working lifetime of about 1-2 hours. For small tool diameters, clogging of the boring for tool shank coolant occurs. As a comparison, the 4mm diameter tool with ultrasonic stimulation could be used up to 9 hours. Superficially, the better rinsing effect and the chip and heat removal is responsible for higher endurance. The high-frequency stimulation of the tool is transferred to the work-piece surface. However, this pattern present on the surface does not lead to a deterioration of roughness parameters.

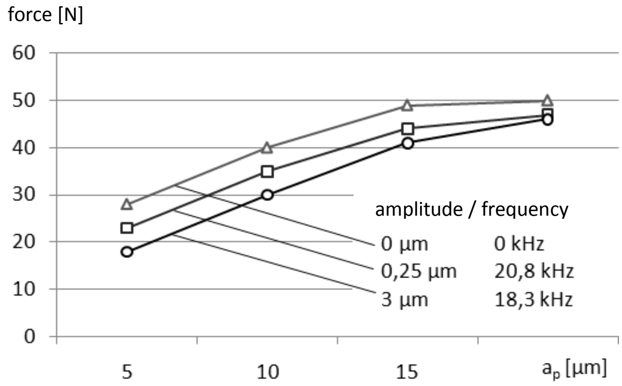

Fig. 3. Influence of ultrasonic on the force in z-direction

Due to the material properties of infiltrated silicon carbide, conventional milling results in significant spalling at the area of contact. This cannot be reduced significantly through the use of ultrasonic vibrations. In this case, we recommend an adjustment of the machining strategy.

5. CONCLUSION

In the optimization of the manufacturing processes, the method of hybrid processing opens a number of opportunities for process engineering influence. The discharge of an ultrasonic vibration in the grinding process causes the appearance of a high-frequency voltage spikes on the cutting grain. This results in short-term increases in compressive stresses in the work-piece material. In brittle materials this results in cavities and micro-cracks. Secondly, the ultrasonic motion also leads to more favorable grain cooling and chip flushing.

The chipping test's cutting data showed discontinuous chips on the order of 1 µm up to 25µm. Therefore an internal coolant supply is recommended. For the processing of infiltrated silicon carbide (SiSiC) it is shown that the ultrasonic vibration as a function of removal rate, while leading to a damping of the ultrasonic motion, achieves significant increases in tool life. The ultrasonic stimulation used here is in the vertical direction (Z axis) to the feed motion.

Further approaches allowing the use of at least two-axis relative movements seem promising. With this knowledge trochoid editing or helical drilling effects could be implemented in a similar high frequency environment.

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