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Generation of thermally effective surface structures by ultrasonic vibration assisted turning

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Abstract

The performance of technical systems is frequently limited by the amount of excess heat that can be dissipated. High potential for an enhanced thermal management is seen in the micro structuring of functional surfaces using ultrasonic vibration assisted turning. The specific structure of the generated surface results in an increased surface area benefiting the heat transfer. Based on experimental investigations it can be concluded that turning with ultrasonic vibration assistance in the direction of the passive force enables significantly increased developed interfacial area ratios *Sdr* due to the micro structures generated. Regarding the feed there is a comparably low influence. Increased vibration amplitudes however result in an additional significant increase of the *Sdr* values. Ultrasonic vibration assistance in turning therefore provides an opportunity for an in-process micro structuring of workpieces involving a considerably increased developed interfacial area ratio. Thus, a more efficient dissipation of excess heat combined with an enhanced system performance is feasible.

Keywords: CVD diamond; Surface area; Surface structure; Thermal management; Turning; Ultrasonic vibration assistance

1. Introduction

For modern technical systems there is a consistent demand for increased performance and efficiency. In many cases the system performance is limited by the ability of dissipating excess heat. One strategy in shifting these limits is the development and application of composite materials providing tailored material characteristics. In addition, considerable potential lies in an appropriate structuring of the functional surfaces. A suitable approach consists in using ultrasonic vibration assistance in cutting processes [1, 2]. Ultrasonic sound is defined by a frequency above 20 kHz. Regarding ultrasonic vibration assistance in cutting processes, typically frequencies in the range of 20 kHz to 100 kHz are applied. In turning typically three separate directions are distinguished in which the ultrasonic vibration assistance can be superimposed. In the present investigations an ultrasonic superimposition in the direction of the passive force is applied. This results in a variation of the depth of cut depending on the amplitude *A* and the resonant frequency f_{US}. Accordingly, this variant is supposed to provide the highest significance in increasing the dimensions of the surface structures.

2. Experiment

Referring to thermal devices, the generation of surfaces with large surface areas is intended. According to the prior section, aiming for a significantly increased thermal efficiency, high developed interfacial area ratios *Sdr* are presumed to be beneficial. In addition, the relation of the *Sdr* values and the line roughness values *Rz* were analysed. For the experimental investigations specimens with a length of 15 mm and a diameter of 28 mm were used. Aluminium alloy AA5754 is used as workpiece material. The specimens were clamped using a pushing collet system. All facing operations were realised with a constant cutting speed using a SPINNER precision lathe PD32 with an integrated ultrasonic device. The resonance frequency of the ultrasonic system is 24 kHz. In the turning experiments, CVD (chemical vapour deposition) diamond tipped indexable inserts with a polished rake face were used, reducing the tendency for the formation of built-up edges. The inserts provide a very sharp cutting edge with a radius of about 3 µm. The type of the inserts used was CCGW with the size 120404. These inserts have a corner angle of 80° and a clearance angle of 7°. The corner radius is 0.4 mm. The tool cutting edge angle of the installed cutting inserts is 95°. All cutting tests were realised using an emulsion as cooling lubricant with a concentration of approximately 5 %, additionally reducing the tendency for built-up edge formation. Based on a fractional factorial design the influencing parameters feed, cutting speed and amplitude were varied according to Table 1. The depth of cut was set to 0.5 mm and kept constant for all experiments.

Table 1. Parameters for ultrasonic vibration assisted turning tests.

Feed f/mm	Depth of cut a_p/mm	Cutting speed v_c/m · min^{-1}	Amplitude A/µm
0.05	0.5	25	0
0.15		50	2
0.25		100	2.9
			3.8

The micro structures generated were analysed using laser scanning microscopy as well as tactile roughness measurements. Additionally, selected surfaces are assessed using scanning electron microscopy. The developed interfacial area ratio *Sdr* was determined based on the 3D data from laser scanning microscopy in an area of 1 mm². For the determination of the line roughness values, ten roughness profiles were evaluated and averaged in the direction of the feed motion (radial) as well as perpendicular to the feed motion (circumferential). Each combination is realised in three repetitive experiments.

3. Results and discussion

For the analysis of the generated surface, the dimensions of the micro structures as well as the overall surface area are of interest. Thus, the surfaces are estimated using the surface roughness values *Rz* and the developed interfacial area ratio *Sdr*, subsequently designated as the area ratio *Sdr*. Due to the high significance the presented results are focussed on the relation of feed *f* and vibration amplitude *A*. Figure 1 shows the influence of the applied feed and an ultrasonic vibration assistance on the surface roughness values in the radial and the circumferential measuring direction.

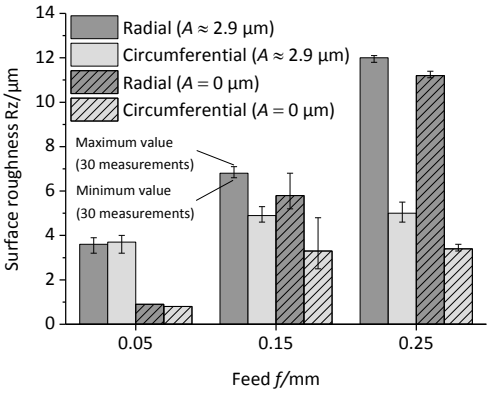

Figure 1. Influence of feed and ultrasonic vibration assistance on the surface roughness values (v_c = 50 m/min, a_p = 0.5 mm).

An increased feed leads to higher *Rz* values, especially in the direction of the feed motion (radial). This is mainly attributed to the increase of the kinematic roughness. For each experimental combination the application of an ultrasonic vibration assistance results in a further increase of the achieved surface roughness values. However, when using a small feed the influence of the vibration assistance is predominant, resulting in the most distinguished surface roughness values. This is attributed to the interaction of the vibration amplitude and the feed. The tool vibration with a constant amplitude results in comparable dimensions of the micro structures for each stage of the feed in the direction of the passive force. However, the increase of the feed leads to a raise of the kinematic roughness. As the feed and thus the kinematic rougness increments the influence of the vibration amplitude on the *Rz* values of the generated surface becomes less significant. Figure 2 presents the area ratio *Sdr* depending on different feeds and the application of an ultrasonic vibration assistance.

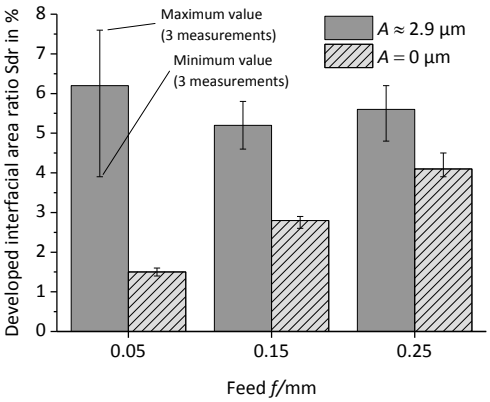

Figure 2. Influence of the feed on the developed interfacial area ratio *Sdr* (v_c = 50 m/min, a_p = 0.5 mm).

Without vibration assistance an increased feed results in higher *Sdr* values. The significant increase can be explained by the increase of the kinematic roughness as well. Respecting the comparably strong variations for the *Sdr* values when using ultrasonic vibration assistance the achieved area ratios are situated in a comparable range. Therefore the applied ultrasonic vibration amplitude provides a more significant influence compared to the feed. Figure 3 shows the surface roughness values depending on different vibration amplitudes applied.

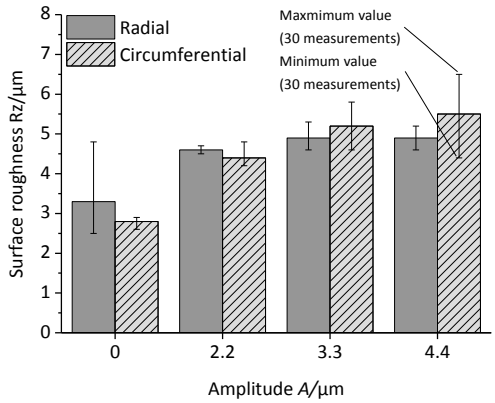

Figure 3. Influence of the vibration amplitude on the surface roughness (v_c = 50 m/min, *f* = 0.15 mm, a_p = 0.5 mm).

As can be seen in machining without vibration assistance, comparably strong variations appear for the *Rz* values in the radial direction, whereas the application of an ultrasonic vibrations assistance leads to significantly increased surface roughness values in both measuring directions with an increase of the applied amplitude. Figure 4 exemplarily presents a SEM image of a surface microstructed by a vibration assisted facing.

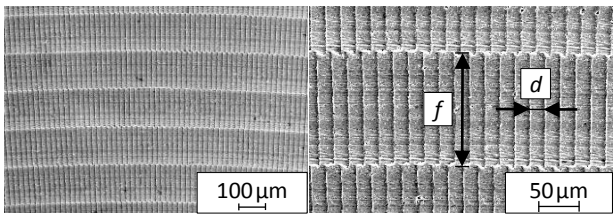

Figure 4. SEM image of generated surface v_c = 50 m/min, *f* = 0.15 mm, a_p = 0.5 mm, *A* = 2.9 µm).

The magnification reveals the feed marks due to the feed *f* in the radial direction as well as the micro structures resulting from the ultrasonic vibration assistance. Parameter *d* describes the circumferential dimensions of the micro structures ranging between approximately 17 µm and up to 70 µm.

4. Summary and conclusions

Investigations in face turning with an ultrasonic vibration assistance in the direction of the passive force have been realised, varying feed, cutting speed and vibration amplitude. An ultrasonic vibration assistance in the direction of the passive force enables a significant increase of the area ratio Sdr. A high amplitude is most relevant for the generation of surfaces with high values for Sdr. In a next step the transfer of the results to smart thermal conductive Al/TPG composites is planned.

Acknowledgements

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