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Comparison of edge formation between conventional and ultrasonic assisted grinding

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Abstract
Ultrasonic assisted grinding is a practically tested and already widely implemented method for enhancing of the material removal rate in the machining of brittle hard / difficult-to-machine materials (glasses, ceramics, crystal materials). In grinding of brittle materials edge chipping cannot be entirely avoided, but it should be minimized to reduce the size of bevels or the costs of finishing operations In this contribution, the edge formation in face grinding with / without ultrasonic assistance of rectangular ZERODUR®-samples was experimentally investigated. The measurement of the edge chipping was made by white-light interference microscopy in a plane parallel to the ground surface and in a plane perpendicular to the ground surface. The graphic representation of the edge contours and the calculated density distribution of these contours show characteristic differences both between grinding with / without ultrasonic assistance and by consideration of various conditions of contact.

ultrasonic assisted grinding; edge formation

1. Introduction

Depending on the requirements of the surface quality, grinding is used for rough machining and/or precision machining processes, especially of hard and brittle materials because of their flexibility in shaping.
Apart from the compliance of dimensional tolerances, as well as shape tolerances and position tolerances and surface quality, also the quality of edges can be important because of technological or function related reasons. It might be assumed that edge formation / edge chipping depends on a variety of factors:

- mechanical properties of the workpiece material, perhaps subsurface damage from pre-machining processes
- geometry and material of abrasive grains
- load of the edge during the grinding process depending on the cutting speed and the material removal rate (cutting depth, feed velocity)
- type of load depending on the relative movement between grinding tool and workpiece and the conditions of contact in the grinding process (compressive stress / tensile stress)
- cooling lubricant and its feed

Practical experiences and a large number of publications prove some technical and economic advantages of ultrasonic assisted grinding (UAG) as a hybrid process in comparison with conventional grinding (CG) for many applications (reduction of grinding forces, grinding temperatures and grinding wheel wear; increase of material removal rate; possibly also enhancement of surface quality / waviness, roughness, surface integrity) [1- 3].
It should be noted that the ultrasonic oscillations of the grinding tool have significant consequences on surface and edge formation of the workpiece.
It was also reported about reduction of edge chipping for UAG under certain conditions. [1]
Due to the wide variety of grinding processes (kinematics, contact conditions, …) it seems that not all conclusions may be generalized or the implementation of the benefits of UAG requires fine adjustment of the grinding and vibration parameters. [4]
The subject of this contribution are comparative studies between UAG and CG with regard to edge formation under defined intervention conditions between grinding tool and workpiece in the case of face grinding with cup wheel.

2. Experimental investigations

2.1. Grinding experiments

The grinding experiments were performed under the following conditions:

- Machine tool: ultrasonic 200 (Sauer GmbH / DMG Mori)
- Samples: 50 mm x 20 mm x 10 mm, Material: glass ceramic Zerodur® (Schott AG)
- Grinding wheel: 6D91-60 M702R (Günter Effgen GmbH)
- cutting speed: v_c = 15 m/s, depth of cut a_p = 0,030 mm, feed rate: v_f = 200 mm / min
- Coolant: Aerolan VS 405

The preparation of the samples was made by lapping of all surfaces of the rectangular samples (alumina oxide ABRALOX F1200) to achieve sharp edges and comparatively low subsurface damage in the initial state.
In the experimental studies face grinding with a cup wheel as conventional grinding (CG) and as ultrasonic assisted grinding (UAG, f = 21 kHz, amplitude approx. 2 µm) was applied. The cup wheel moved with its centre point along the edge during the grinding process. In this way the impact / escape of the abrasive grains was perpendicular to the edge with defined loads at the beginning (impact) / end (escape) of the material removal by the abrasive grains (Figure 1).
In case of the impact of the abrasive grains, a dominant compressive load is to be expected and in case of the escape of the abrasive grains, a correspondingly dominant tensile load is to be expected.

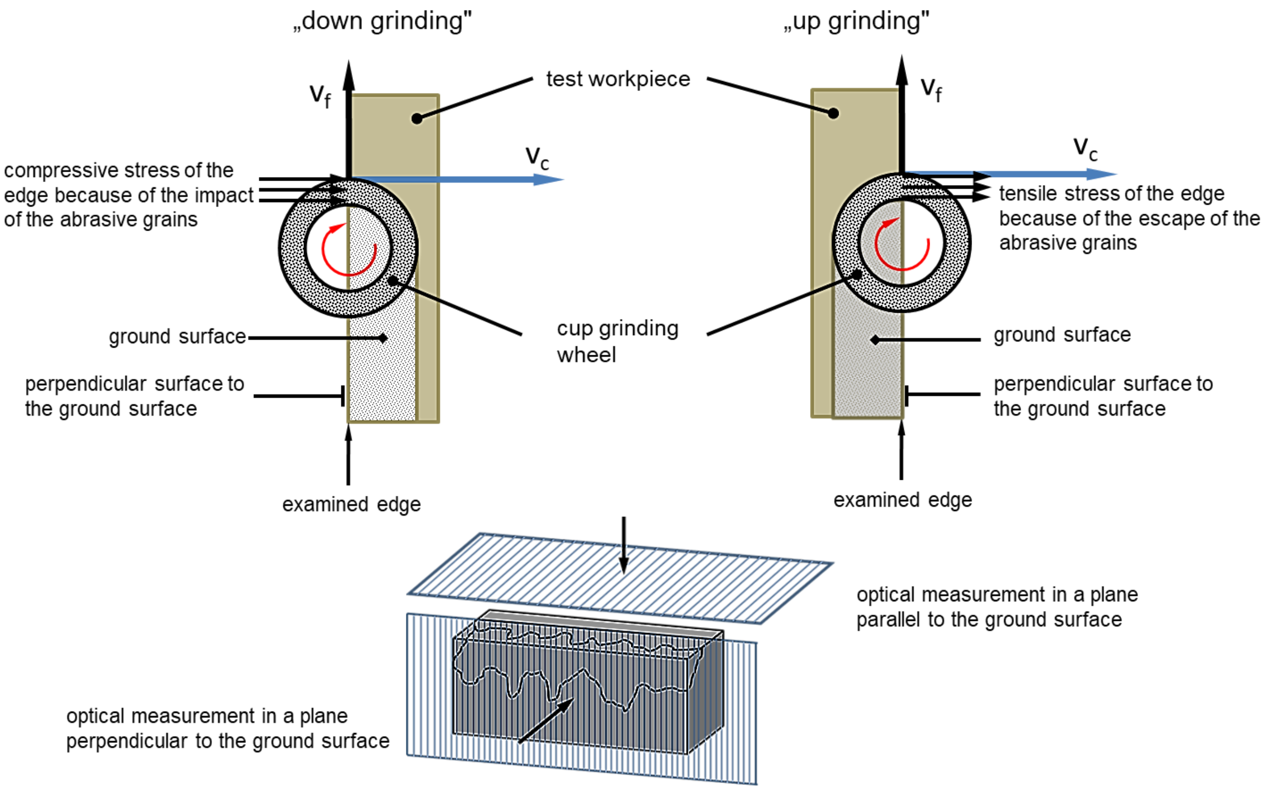

Figure 1. Schematic presentation of the grinding experiments set up and the measuring method for edge survey

2.2. Measuring method for the edge chipping

The measurement of the edge chipping was carried out with a white-light interference microscope (Talysurf CCI-HD / Ametek Taylor Hobson) by stitching measurement with a line of overlapping single measuring fields along the edge over the whole length of the samples (50 mm) in two planes (ground surface and the corresponding perpendicular surface). (Figure 1)
The contours of the edge chipping were computed on the base of these 3D-data for the middle section with a length of 40 mm. The graphical presentation there comprises a section of 25 mm. (Figures 3; 4)
The additionally computed distributions (density distribution functions) of these contours enable an objective assessment of the edge chipping. The reference lines for these contours are the traces of the corresponding perpendicular surfaces (planes) in the respective measuring plane. The reference lines comply with the x-axes in the graphical presentations. (Figures 3-6)

3. Experimental results

It is to be expected that the specific intervention conditions between grinding wheel and workpiece lead to different loads at the edges and consequently to different characteristics of edge chipping.
However, SEM-photographs of the edges do not show noticeable distinction between UAG and CG, maybe because of the limited picture section. (Figure 2)
In contrast, the review of the measured contours of edge chipping reveals significant differences. (Figures 3; 4)
The following statements can be derived from the experimental results:

- edge chipping measured in the plane of the ground surface is less distinctive compared with the edge chipping in the plane perpendicular to the ground surface
- edge chipping on edges with compressive load (impact of the abrasive grains) is less distinctive compared with the

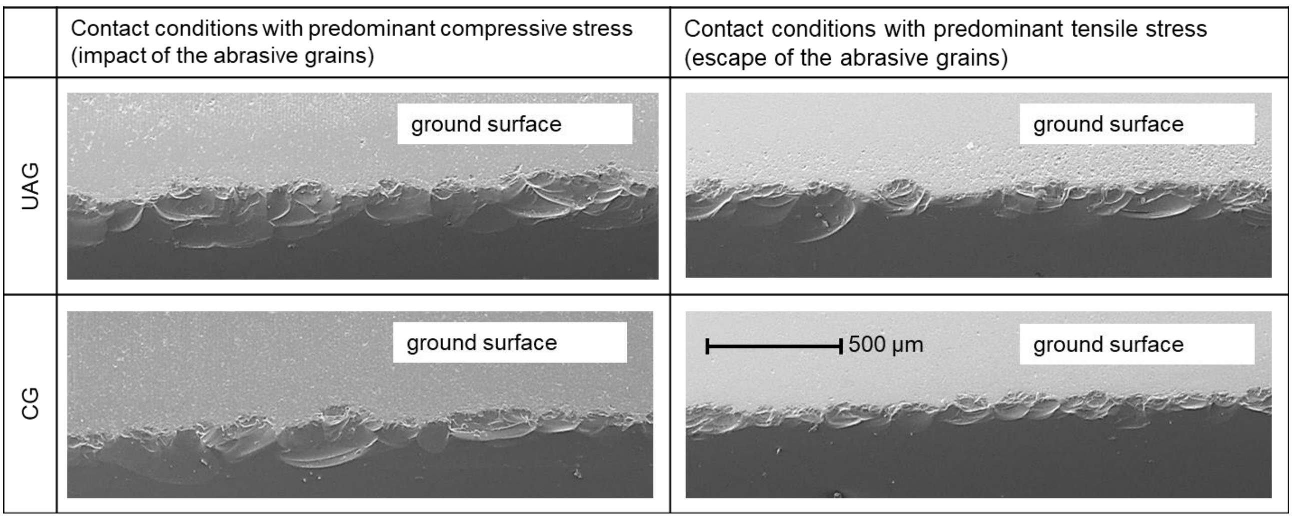

Figure 2. SEM-photographs of the edge chipping for different grinding processes and contact conditions (magnification: 50 x)

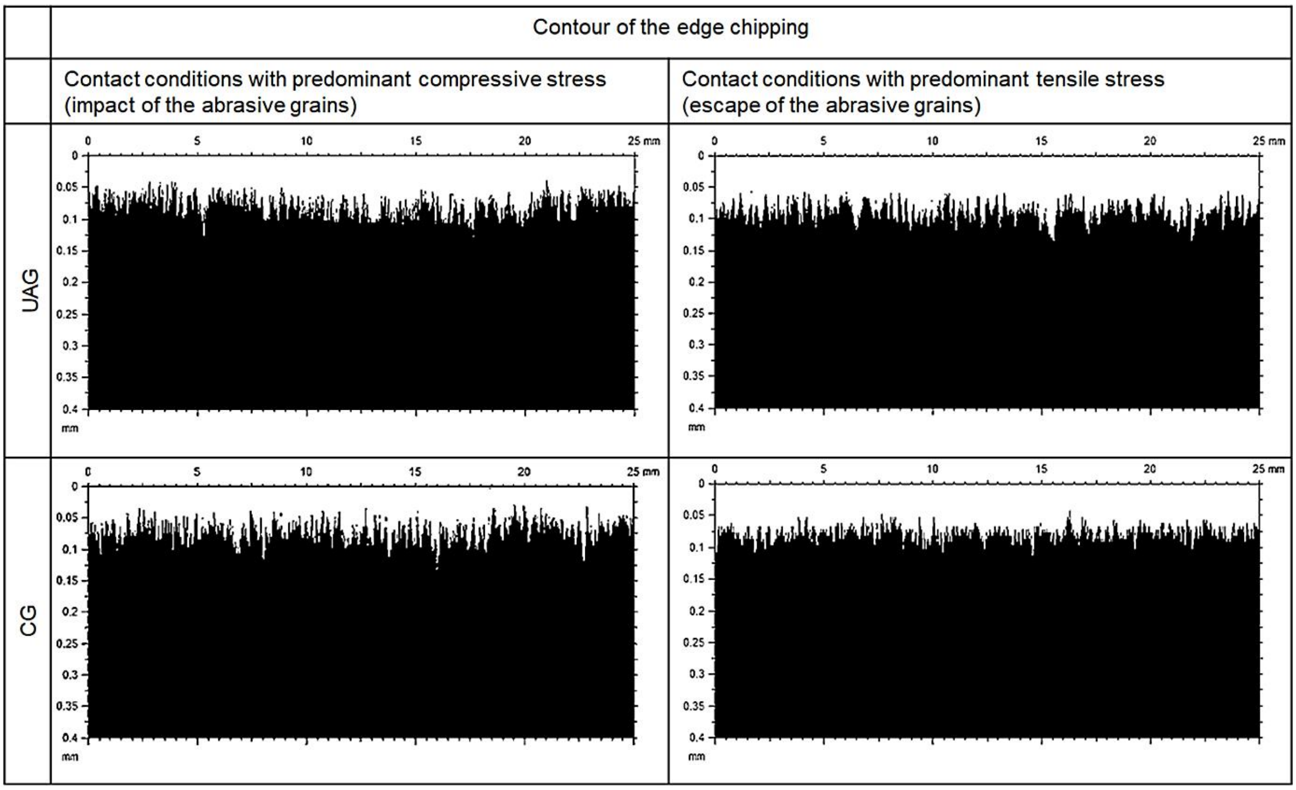

Figure 3. Measured contours of edge chipping for different grinding processes and contact conditions, Measurement in the plane of the ground surface

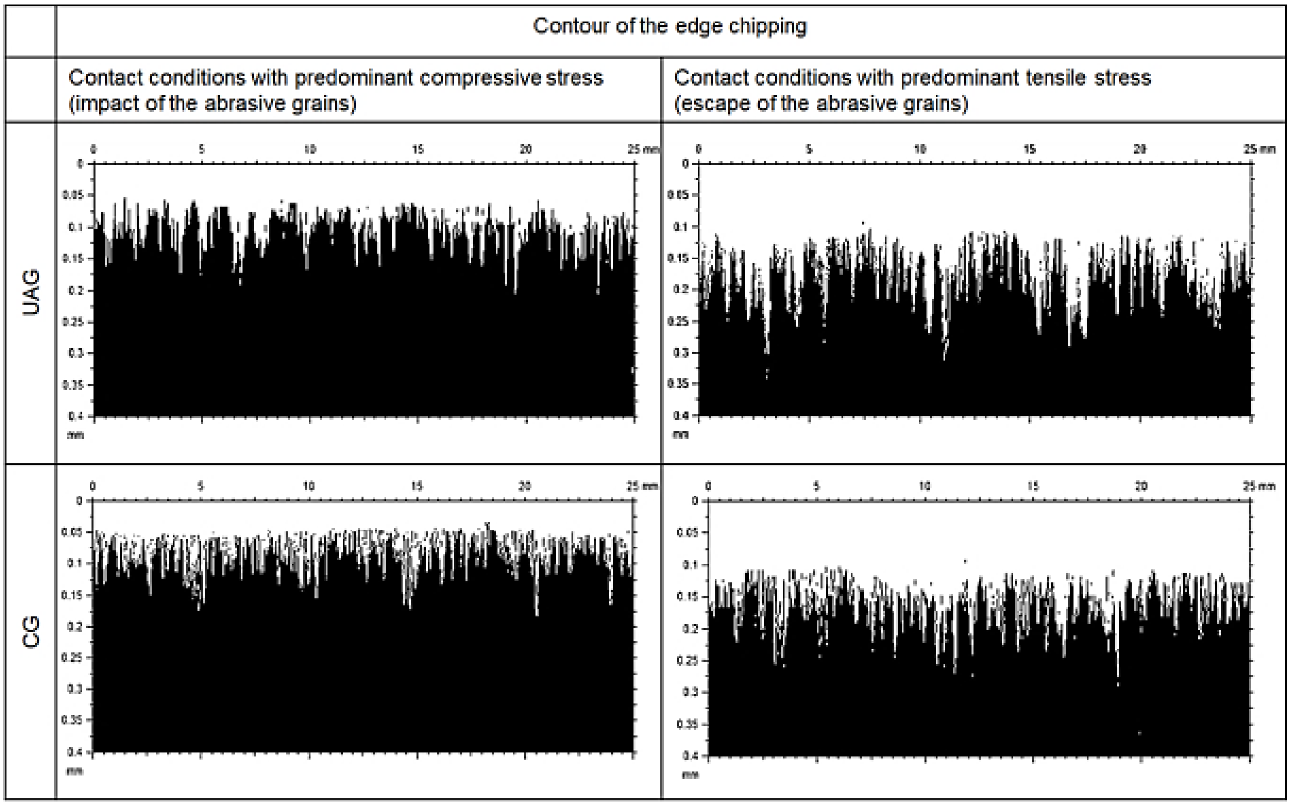

Figure 4. Measured contours of edge chipping for different grinding processes and contact conditions Measurement in the plane of the surface perpendicular to the ground surface

edge chipping on edges with tensile load (escape of the abrasive grains). This has to be seen in connection with the typical behaviour of hard and brittle materials

- In case of UAG, the edge chipping is apparently greater compared with CG. Marked edge chipping means both the difference between the upper envelope of the contour and the reference line and between the lower envelope and the reference line are larger.

One plausible reason for this may be the modulation of the depth of cut by the axial oscillation of the grinding tool (perpendicular to the ground surface)

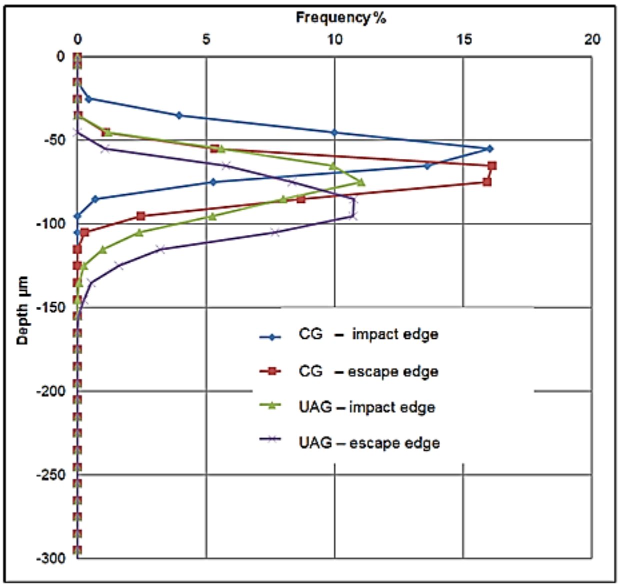

Figure 5. Density Distributions of the edge chipping contours measured in the plane of the ground surface for conventional and ultrasonic assisted grinding

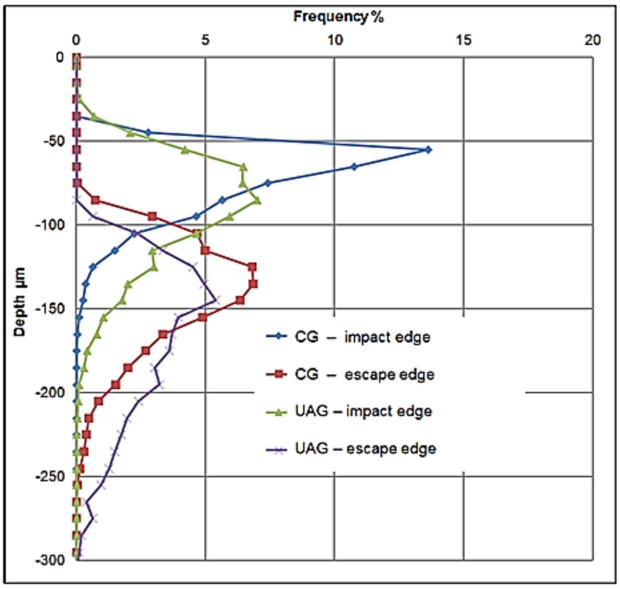

Figure 6. Density Distributions of the edge chipping contours measured in the plane of the surface perpendicular to the ground surface for conventional and ultrasonic assisted grinding

These cause-effected relationships become also clear in the presentations of the density distributions of the edge chipping contours. (Figures 5; 6)

4. Conclusions

The experimental investigations show that UAG does not necessarily lead to better machining results. With regard to edge chipping the kind of load on the edges (compressive stress / tensile stress) depending on the specific cinematics and the conditions of contact in the grinding process should be noted. In practical machining operations, there are solution approaches by the determination of tool paths, which lead to favourable contact conditions. Furthermore, the last overrun of the grinding tool can be made without ultrasonic assistance to avoid unfavourable conditions concerning edge chipping.

References

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