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Grinding Tool Structuring

Konrad Wegener and Christian Walter
Institut für Werkzeugmaschinen und Fertigung (IWF), ETH Zürich, Zürich, Switzerland

Definition

Tool structuring is a conditioning process for grinding wheels, where defined patterns of abrasives or of clusters of abrasives on the wheel surface are generated in order to influence the cutting performance and cutting characteristics of the wheel.

But structuring not only means that a manufactured tool is postprocessed. Manufacturing of engineered grinding tools (EGT) is also classified as generation of structured grinding tool.

Theory and Applications

In literature, the structuring process is often categorized under profiling, because it creates part of the macrogeometry. However, in extension to the classification according to VDI 3392 (2007), herein structuring is treated as a separate conditioning process as shown in Fig. 1, in order to reflect its specific influence on the tool with respect to grinding properties and tool geometry. The result is totally different from that of generation of macrogeometries and also differs from sharpening results.

The purpose of structuring is to enhance the cutting conditions on the tool surface by increasing the chip thickness per grain, thus according to Kienzle equation reducing the overall cutting forces and thereby the overall grinding efficiency. This means that heating and heat damage of the workpiece is reduced as has been shown by Rabiey (2010). Moreover, chip flow and coolant flow conditions are expected to be improved. But structured grinding wheels normally generate worse surface quality and are subject to higher wear as the number of active cutting edges is reduced.

There are in principle two methods for producing a structured wheel surface:

In the first method of structuring, hereafter referred to as the direct method, is such that the structuring of the wheel surface is part of the manufacturing process of the grinding wheel shape. This can be realized by, e.g., a segmented die/mold shape, separate abrasive segments that are applied onto the wheel body, or even single abrasive grits that are arranged in defined patterns on the wheel's surface. The direct method is usually limited to macroscopic structuring and segmentation for multilayered wheels. For monolayered surface-set wheels, engineered grinding tools (EGT) present an approach to design specific wheel topographies on the microscale.

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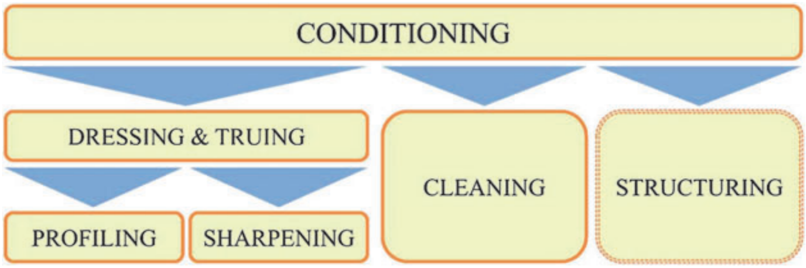


Grinding Tool Structuring, Fig. 1 Classification of grinding wheel conditioning processes according to VDI guideline 3392 (2007), complemented by structuring as an additional process according to Walter et al. (2014)

The second method of structuring, hereafter referred to as the indirect method, starts from a non-structured wheel of cylindrical or other shape. The surface structuring is then applied by means of a material removing process. Usually these are mechanical structuring processes utilizing a dresser. In principle, structures ranging from the macro- to the microscale are possible. However, the minimal dimensions of the generated structures are restricted to the dimensions of the dressing tool in combination with the kinematic conditions of the dressing setup.

Conventional Structuring

In 1936, Sherk (1936) patented a slotted abrasive wheel shown in (Fig. 2) left with different slot arrangements to enable higher grinding material removal rate. Nakayama et al. (1977) studied the influence of helical grooves (width 2–2.5 mm) on the grinding performance of a conventional vitrified bonded wheel. A reduction in grinding forces by approximately 30% was achieved, and no significant deterioration in surface quality or increase of wheel wear was observed.

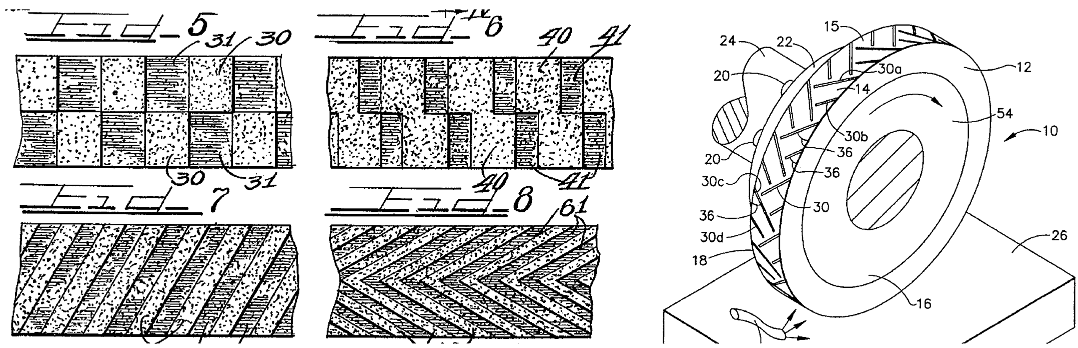
The effect of the wheel topography and axial grooves (width 3 mm, depth 0.5 mm) on the cooling efficiency in surface grinding was studied by Okuyama et al. (1993). It was found that the heat transfer coefficient increases with the number of grooves, and it was thus concluded that coolant is accumulated and transported through the grooves. In line with these results, Lee et al. (2000) measured up to 80% lower grinding temperatures in face grinding of alumina with slotted diamond wheels.

A thermal model for grinding with slotted/segmented wheels was developed by Zheng and Gao (1994). Due to the periodic intermittent rise of the grinding temperature for slotted wheels, the heat accumulated in the grinding zone was reduced. In addition, simulation results indicate that the slotting factor (reduction of the wheel's surface due to segmentation) has a stronger influence on the grinding temperature than the pitch of the segmentation.

Kim et al. (1997) proposed a manufacturing method for a discontinuous grinding wheel for grinding ductile metals, wherein the segments are filled with an abrasive matrix of high porosity, which wears quickly in the grinding operation and thereby results in a discontinuous cutting process.

The concept of dead-end grooves on the wheel surface, with the purpose to feed and trap coolant in the grooves, in order to reduce workpiece burning during creep feed grinding, was introduced by deGraaff (1997). A similar approach with various pattern geometries was proposed by Fischbacher and Noichl (2001).

Several researchers (Aurich et al. 2003, 2008; Burkhard et al. 2002; Pinto et al. 2008) developed brazed or electroplated monolayer EGT with defined grain patterns, applied in power honing and high-performance grinding. Some tools were designed and optimized based on kinematic process simulations. The grain rows were usually arranged in a helical pattern at a pitch angle of 15° to 30° and spacing between the grains and grain rows between 0.3 mm and 2 mm, depending on the grain size. Experimental results and simulation models led to the conclusion that grinding forces can be significantly reduced with EGT;



Grinding Tool Structuring, Fig. 2 Grooved wheel geometries proposed by Sherk (1936) (left) and deGraaff (1997) (right)

however, even for an optimized grain pattern, the workpiece surface finish will not be better than that obtained with a conventional stochastic electroplated wheel as shown in Koshy et al. (2003).

Tawakoli et al. (Tawakoli and Rabiey 2008; Tawakoli et al. 2007) proposed a crossed helix structure (width 0.6–1.5 mm, pitch 0.8–1.9 mm, depth 0.03 mm, pitch angle 60°) on resin and vitrified bonded CBN wheels for dry grinding of hardened steel. Due to a significantly reduced wheel surface area (down to 25%) that can be achieved by this method, grinding forces and workpiece burning in dry grinding were reduced. However, an increase in workpiece roughness and radial wheel wear were the consequence.

(a) Nd:YAG laser structured.

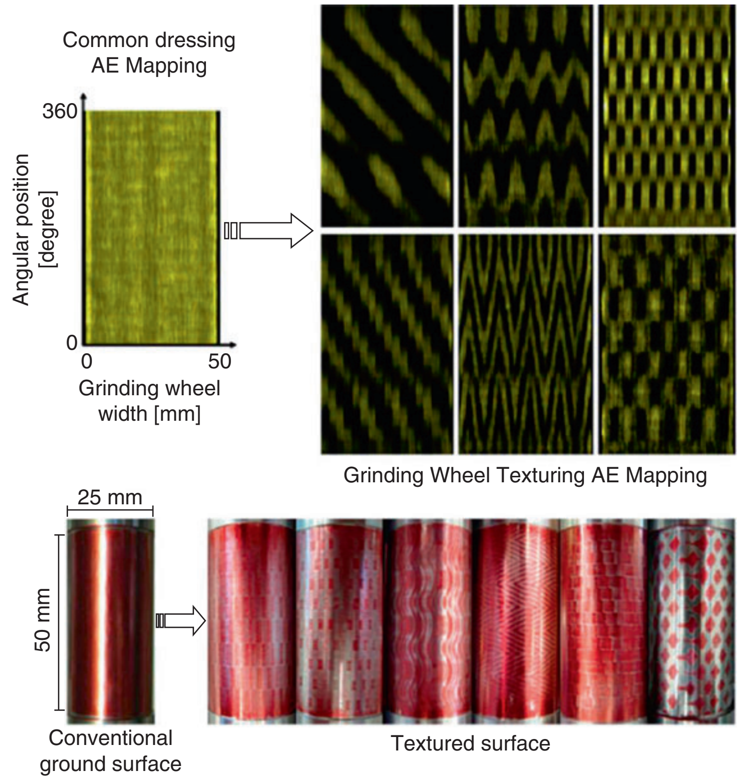
Oliveira et al. (2010) and Silva et al. (2013) introduced a novel dressing technique utilizing an electromechanically excited diamond dresser to engrave various patterns onto the grinding wheel surface. The dimensions of the patterns were limited by the dynamics of the exciting system and the dimension of the dresser. Minimum feature sizes of 0.5 mm in the axial and 2 mm in the circumferential direction were achieved at depths between 2 μm and 25 μm. The comparison of grinding power and workpiece surface roughness for different patterns showed that a decrease of the former results in an increase of the latter. In a specially designed plunge grinding operation, it was also demonstrated that the wheel pattern can be directly replicated onto a cylindrical workpiece, which can be seen in Fig. 3. A similar approach toward regular surface texturing by grinding with circumferentially grooved wheels was investigated by Stepien (2007).

Research work by Mohamed et al. (2013) studied the influence of circumferential grooves on the creep feed grinding performance of vitrified alumina wheels at different wheel surface areas (100%, 70%, and 50%). The grooves were produced using a single-point diamond dresser. Depending on the reduction of wheel surface area, the consumed grinding power was reduced by 30–60% compared to a non-grooved wheel. Interestingly, besides an increase of workpiece roughness, no increase in wear rate was observed for the grooved wheels.

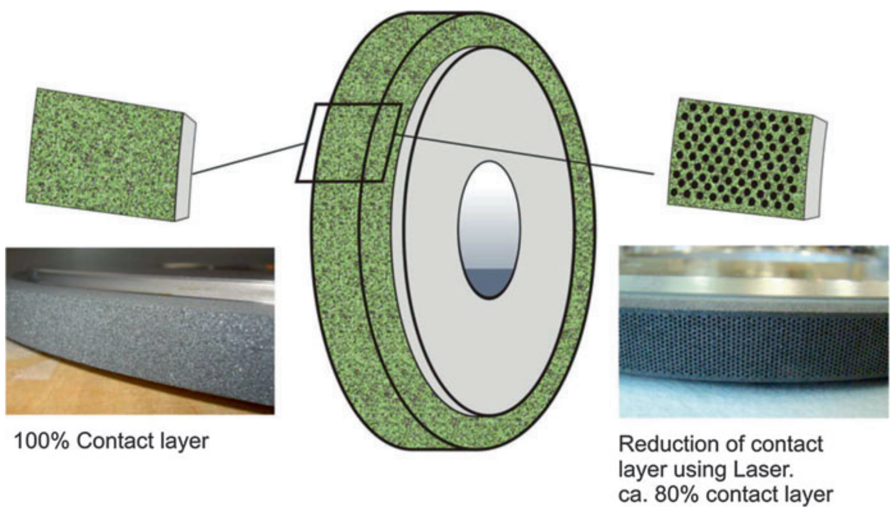
Aurich and Kirsch (2013) demonstrated a significant improvement of the coolant supply on electroplated CBN wheels by milling slot-shaped pockets into the base body of the grinding wheel.

Laser Structuring

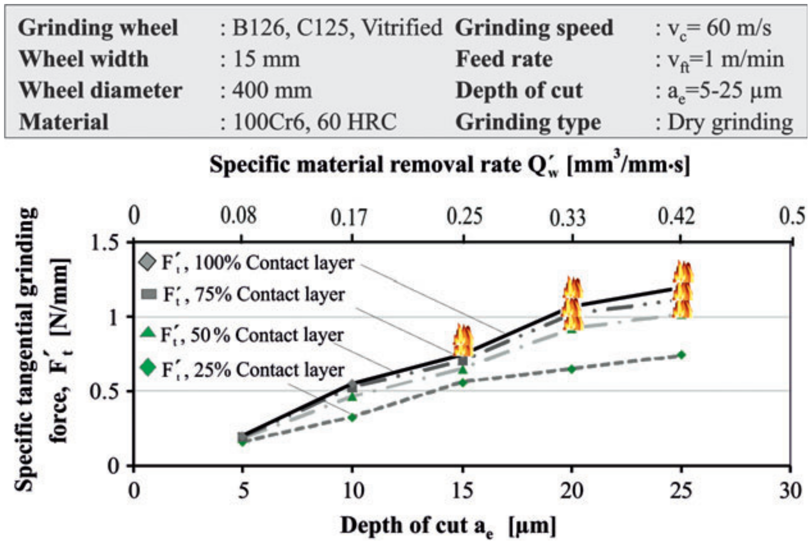
Rabiey (2010) for the first time utilized a laser for structuring of grinding tools. In this study, a long pulsed Nd:YAG laser was used to drill blind holes (diameter 500 μm, depth 5 mm) into a large vitrified CBN wheel, with the intention to produce coolant reservoirs in the abrasive layer as shown in Fig. 4. At approximately 80% wheel surface area of the structured wheel, a significant reduction of the heat-affected zone on the workpiece was achieved. However, increased workpiece roughness and profile wear must be taken into consideration. Figure 5 shows the reduction of



Grinding Tool Structuring, Fig. 3 AE mapping of wheel texturing and textured workpiece surfaces from (Oliveira et al. 2010 and Silva et al. 2013)



Grinding Tool Structuring, Fig. 4 Nd:YAG laser structured wheel surface rom (Rabiey 2010)

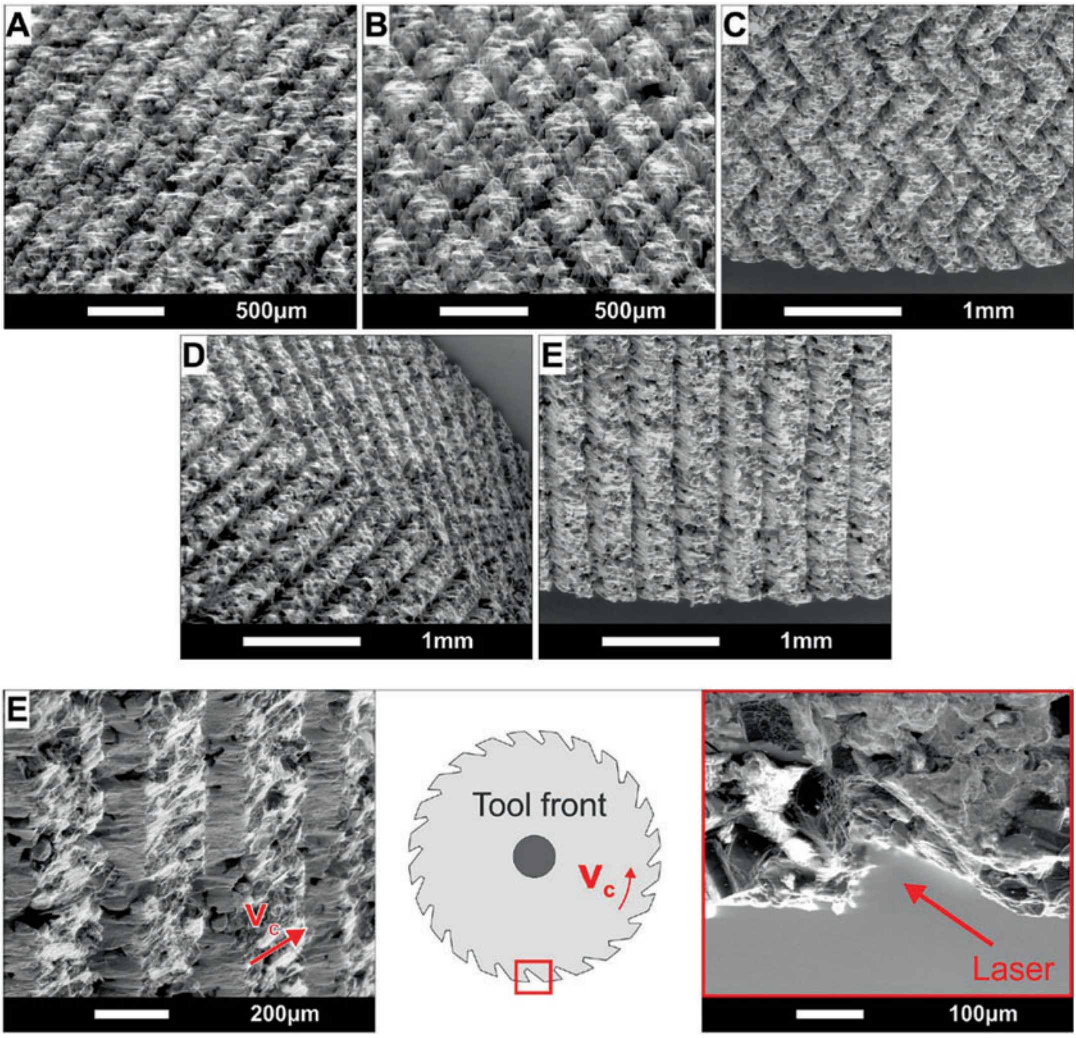


Grinding Tool Structuring, Fig. 5 Reduction of specific tangential grinding force due to structuring as function of cutting depth. The flame symbol indicates situations leading to grinding burn of the workpiece (Rabiey 2010)

forces and heat load achieved. Rabiey also reports that the residual stresses in the workpiece subsurface are significantly reduced, which means shifted from tensile stresses more to compressive stresses.

Walter et al. (2014) and Walter (2014) investigated surface structuring of small hybrid bonded CBN grinding tools using ultrashort picosecond pulsed laser processing. It was shown that this laser process does affect the integrity of the grain-bond structure due to thermal effects. The grinding results indicate a much stronger influence of the pattern layout on the grinding behavior compared to the influence of the degree of surface structuring of the tool surface. Figure 6 shows different patterns created by laser structuring. Pattern E shows that with structuring also the cutting edges can be shaped on average, to give a directional behavior of the grinding wheel.

Guo et al. (2014) reported on grinding of optical glass by means of laser structured coarse grain electroplated diamond wheels. A nanosecond pulsed laser at 355 nm wavelength was used to ablate 10–15-µm-wide circumferential grooves into a wheel with 150 µm grain size. A higher surface roughness but less subsurface defects in the ground glass was observed when grinding with the structured wheel.



Grinding Tool Structuring, Fig. 6 Different patterns from laser structuring of hybrid bonded CBN grinding wheels. Especially pattern E shows that also cutting edges may be shaped by structuring (Walter 2014)

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