Micro-Structured CBN Grinding Wheels for the Production Grinding

1. Introduction

The grinding technology has been in a growing fierce competition at an increasingly higher technological level with other cutting processes for several years. Despite the partial substitution of grinding by other machining methods (e.g. hard turning), the grinding processes with ultra-hard materials (diamond and cubic boron nitride CBN) could significantly extend their fields of application for the following reasons:

- Trend towards higher accuracies
- Increased use of difficult-to-cut materials
- Integration of high-performance grinding processes into existing process chains (e.g. rough grinding)
- Combination of pre-machining and fine machining to one single grinding process

Despite these successes, the grinding process with ultra-hard materials faces specific problems in view of new market fields.

The classification of machining methods according to DIN 8580 shows that grinding is a process with a geometrically undefined cutting edge.

![Classification of manufacturing and machining processes according to DIN 8580](image)
The parameters determining the machining process are based on complex distribution functions such as:

- Grain size distribution
- Grain elongation, i.e. the relation between the longest and the shortest grain axis
- Cutting edge distance
- Cutting space depth

Fig. 2: Measured length of the short grain axis (measured B126) [1]

Fig. 3: Frequency distribution of the longitudinal elongation coefficient measured for the grain sizes B91, B126, B151 and B181 [1]
These stochastic properties which can be found in the micro-topography of the grinding wheel, lead to the fact that particularly high-performance grinding is often a very complex and difficult process in terms of a deterministic description. This implies complicated kinematic conditions between the tool and the workpiece as well as a variety of external influencing factors (e.g. the coolant supply, workpiece vibrations etc.).
In order to meet these difficulties of high-performance grinding and to open up further fields of application, machinery and tool manufacturers have developed numerous measures and solutions including:

- improved dressing technologies for the creation of reproducible micro-topographies on the grinding wheel grains,
- the development of an advanced sensor and control system by means of structure-borne sound, vibration, force and temperature measurement,
- the improvement or development of the grinding tool by use of new bond types and abrasive grains. The objective is to obtain almost constant micro-topographies between the longest possible dressing intervals.

With regard to the latter point, the Diamant-Gesellschaft Tesch GmbH has developed as part of several research projects grinding tools which combine the usually stochastic grain bond structure with an ordered micro-structure.
2. Motivations and objectives of the development of structured CBN grinding wheels

The point of departure for the development of structured CBN grinding wheels were the following market demands:

- Reduced influencing of the peripheral zone of the workpiece (grinding burn, micro-magnetic analysis of the surface area).
- Minimisation of the cooling lubricant use.
- Reduction of the cycle times when using the grinding tool very differently during a process (pre- and finish grinding by means of one tool).
- Increased machining of difficult-to-cut materials.

In a fundamental study three technologies have been examined:

A. Electroplated CBN grinding wheels with geometrically defined grain structures

B. Electroplated CBN grinding wheels with structured basic bodies
C. CBN multilayers with an integrated micro-structure

All these technologies share the reduction of negative cutting angles on the surface of the grinding wheel (i.e. rubbing crystals) as well as the creation of an additional chip space. This results in a reduction of the grinding forces and also a reduction of the heat input. In industrial practice particularly the use of CBN multilayers with micro-structure shown under C have already yielded interesting successes.
3. **Micro-structured layers of vitrified CBN grinding wheels**

When optimising vitrified CBN layers, the engineers meet the conflicting requirement that they have to realise on the one hand as open structures as possible, i.e. high porosity, and on the other hand the highest possible grain retention forces. This is usually tried by the use of bond systems being resistant to high specific stress and not requiring too high firing temperatures. However, there are physical limits to these developments and high grain retention forces still need denser structures with the known effects such as high normal grinding forces and high heat input.

The creation of additional porosity with a sharp upper pore size within a defined geometric pattern can partially solve the dilemma between high grain retention forces and low heat input. The main reasons are the better transfer of the cooling lubricant to the machining area as well as the different pore size distribution on the basis of a natural porosity and an artificially produced micro-structuring. The micro-structuring with pore diameters from 0.2 mm – 0.5 mm and a spacing between 1 mm and 2 mm was examined as part of the present study.

Fig 6: Topographies of grinding layers with vitrified bond concepts
Fig. 7: CBN grinding wheel with a geometrically defined pattern of mesopores
3.1 Laser structuring of vitrified CBN layers

Since a considerable proportion of ultra-hard material in vitrified CBN layers (up to a volume of 48%) renders a mechanical machining impossible from the economic point of view, and due to the fact that sufficiently fine structures cannot be produced by means of the water jet technique, the laser machining proves to be an appropriate technology. However, the following technical constraints have to be taken into account:

- Lower heat input into the bond in order to avoid cracks in the vitro-ceramic structure
- No disruption of the CBN crystals
- As constant as possible cross sections of the micro-structures also in the depth (up to 10 mm)
- Short 'drilling' times

Fig. 8: Cross section of a laser drilled vitrified CBN layer (hole spacing 1 mm)
In order to meet also the demand for economic efficiency, the machining time per hole has been reduced from initially approx. 2 – 3 s to approx. 0,15 – 0,3 s with a hole diameter of 0,3 mm and a hole depth of 6 mm.
4. Grinding technology results of laser structured CBN grinding wheels

As part of a diploma thesis at the University of Furtwangen [2] two CBN grinding wheels of the same specification with and without micro-structuring were compared during a surface grinding process with regard to specific grinding forces.

The applied micro-structure was very dense, it reduced the active wheel surface by 18 – 20%.

Fig. 10: Grinding forces depending on the material removal rate [2]

These results provide evidence of the values to be found in the industrial environment:

- Reduction of the normal grinding forces by approx. 25% with a surface reduction of 8 – 10% and up to 50% with a surface reduction of 20%.
- No or negligible low increase of the Rz value (< 0,2) during the external cylindrical grinding, even a reduction during the surface grinding.
- No wear increase of the grinding wheel (with a surface reduction < 12%).
- Significant reduction of the thermal influencing on the workpiece (verified through Stresstech measurements).
- Increase of the tool life (up to 200%) during the grinding of concave camshafts, provided that the thermal influencing is an essential dressing criterion.
- Reduction of the grinding time by up to 25% in case of unstable parts.
4.1 Additional optimisation possibilities for grinding processes by means of laser structured layers

Since the laser structure is being applied to the layer after its production, there is the possibility to adjust the properties of the layer areawise to the situation of the grinding allowance and other process requirements.

Fig. 11: Areawise adjustment to the grinding process or the workpiece
5. Summary and Outlook

The micro-structuring of the abrasive layers of grinding wheels provides additional knowledge about the parameters for the optimisation of grinding processes. Particularly, laser structured vitrified CBN grinding wheels became considerably important in the machining process of concave camshafts. The adjustment of abrasive layers to different situations of the grinding allowance is currently being tested by several manufacturers of truck crankshafts with tangent radii.

Other advantages of the laser structuring will be developed using adjusted cooling nozzles (shoe nozzles or free jet nozzles) with an adjusted angular position or micro-holes. Preliminary results indicate a potential reduction of the coolant flow up to 80%.

In addition, the applicability of micro-filled solid lubricant (MoS₂) will be examined during dry grinding processes.

Due to the complexity of the grinding processes, some grinding processes currently show no improvement when using micro-structured wheels. This concerns in particular the machining of very rigid heat resistant workpieces.

The study of the optimum feed geometry of the coolant in the machining zone may also identify a potential for the optimisation of these processes.

Fig. 12: Improved coolant loading by means of the angular position of the micro-holes
6. Literature

[1] Zitt, U.
Modellierung und Simulation von Hochleistungsschleifprozessen
FBK-Produktionstechnische Berichte, Band 34,
Herausgeber Prof. Dr. Ing. G. Warnecke,
1999.

Trockenschleifen mit einer laserbearbeiteten Schleifscheibe,
Diplomarbeit Hochschule Furtwangen.

Möglichkeiten zur verbesserten Nocken- und Kurbelwellenbearbeitung
durch neue CBN-Schleifscheibenkonzepte,
Interne Notiz Diamant-Gesellschaft Tesch GmbH.