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High Performance Grinding

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Abstract

The efficient processing of innovative materials, the further development of grinding tools and machine concepts as well as an increasing economic and environmental pressure are current challenges in grinding technology. High Performance Grinding processes offer a huge potential to overcome these challenges and increase productivity. They are characterized by a significant increase in material removal rate and component quality plus a reduced need of resources. In this paper, possibilities are presented and discussed for extending the process boundaries of conventional grinding processes in order to create High Performance Grinding processes. Based on current research, potentials to increase productivity of conventional grinding processes are described. In addition to process-specific optimization of the machine and the grinding tools, opportunities are pointed out for the numerical prediction of the process boundaries as well as methods for mathematical interpretation and analysis of grinding wheel structures and topographies. Moreover, opportunities are presented for future increases in productivity by combining High Performance Grinding processes with other manufacturing technologies.

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1. Introduction

In order to maintain the competitiveness of high-wage countries in global markets, the manufacturing cost must be kept low with rising labor expenses. At the same time the range of products is increasing rapidly while the product lifecycles decrease. So, the competitiveness of manufacturing companies depends on their ability to adapt to swiftly changing global conditions [1].

High precision machining with geometrically undefined cutting edges represents a key technology to meet these challenges. Continuously increasing quality and cost reduction demands, especially in automotive, bearing and aerospace industries, require enhanced processes that provide optimal yield. Usually, the aim is to maximize the production rate while maintaining the specified product quality frame and to reduce the cost and time of the production simultaneously. High Performance Grinding (HPG) processes expand the field of grinding from traditional finishing operations to highly efficient and high-precision machining.

Current developments have led to new grinding challenges which refer to the configuration of improved processes with high performance capabilities [2]. Depending on the requirements, competitive grinding processes need to be allocated to highly efficient processes with maximized material removal rates or to high-precision processes for outstanding surface qualities.

The present paper provides the fundamentals of grinding and lists the characteristics of High Performance Grinding processes from a scientific point of view. In the following, the driving factors for HPG processes are discussed. It is shown how to react to recent challenges in grinding by new tool and process designs. Furthermore, the high potential of a model-based optimization of grinding processes is laid out. In addition, strategies how to identify the material behavior of innovative and unique materials are presented and the potential of a combination of grinding with other manufacturing processes is discussed.

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Nomenclature

A_{c1b}	Austenite start temperature
A_{c1e}	Austenite finish temperature
a_e	Depth of cut
$a_{e,\,tot}$	Total depth of cut
$a_{e,\,min,\,crit}$	Critical depth of cut
A_{ni}	Specific cutting edge area in normal direction
A_{ti}	Specific cutting edge area in tangential direction
d_f	Diameter of the glass fiber
E_{pulse}	Pulse energy
ε_{lim}	Limiting angle of cutting edge offset
f_{pulse}	Pulse frequency
$F_{n,S}$	Normal cutting force
$F_{t,S}$	Tangential cutting force
h_{cu}	Chip thickness
HPC	High Performance Cutting
HPG	High Performance Grinding
HSC	High Speed Cutting
N_{kin}	Kinematic cutting edge count
PCD	Polycrystalline diamond
Q'_w	Specific material removal rate
Ra	Average roughness height
r_w	Workpiece radius
SSD	Sub-surface-damage
t_{pulse}	Pulse duration
$\dot{T}_{up/down}$	Heat-up/Heat down rate
T_μ	Grain cutting depth
v_c	Cutting speed
v_f	Axial feed rate
v_s	Circumferential speed of the grinding wheel
v_w	Workpiece speed
V'_w	Specific material removal
$v_{w,crit}$	Critical table speed

2. Fundamentals of grinding

Knowledge of the fundamental principles of grinding is essential to tap the full potential of High Performance Grinding (HPG) processes. Considering the grinding process with all its components, such as grinding wheel, process parameters or cooling lubrication, as a series of “resistors”, it becomes evident that the system “grinding” can show its full potential only if all these resistors are optimized. Therefore, it is necessary to know the influence of each component on the ground workpiece. Due to the high complexity of the grinding process caused by machining with geometrically undefined and stochastically distributed cutting edges, the process design and process control of HPG processes is very challenging.

During the engagement of only one grain with the workpiece material, the grain first deforms the ground material elastically and plastically before a chip is formed from the surface of the workpiece (Figure 1). This process is repeated countless times per second. This leads to a permanent superposition of engagements [3]. A direct observation and determination of these processes was recently monitored in detail by Denkena [4]. Beside the generation of a surface finish, the contact conditions between the grains and the workpiece material generate a thermo-mechanical load on the workpiece. This thermo-mechanical load determines the functionality and the application characteristics of the workpiece. Among other things, the thermo-mechanical load depends highly on the topography of the grinding wheel, which in turn depends on the grinding tool specification, the grinding conditions and the dressing conditions [5].

High performance grinding processes are often designed to maximize material removal rates or to optimize surface qualities. Therefore, many processes are designed by varying the “resistor” process parameters. One possibility to increase the efficiency of a grinding process is to increase the circumferential speed of the grinding wheel v_s. An important advantage of increased productivity due to grinding at high cutting speeds (HSC) is the increased grinding wheel tool life because of decreasing single grain loads [5,6]. The most significant disadvantage of increasing the circumferential speed v_s is the rising thermal load acting on the surface layer of the workpiece. Corresponding countermeasures are necessary to avoid a damage of the workpiece, when increasing v_s. An appropriate strategy to reduce the thermal load on the workpiece surface layer lies in the increase of the workpiece speed v_w (HPC). This way, the single grain load increases slightly, but the process temperature can be lowered significantly. Additionally, the related material removal rate can be increased without damaging the workpiece material. Thus, when varying one of the process parameters, the influence on the thermo-mechanical load acting on the workpiece must be considered. In most cases, this entails the adaptation of at least one other “resistor” such as another process parameter or the specification of the grinding tool. Only with a methodical approach it is possible to extend conventional grinding processes and to achieve reliable HPG processes.

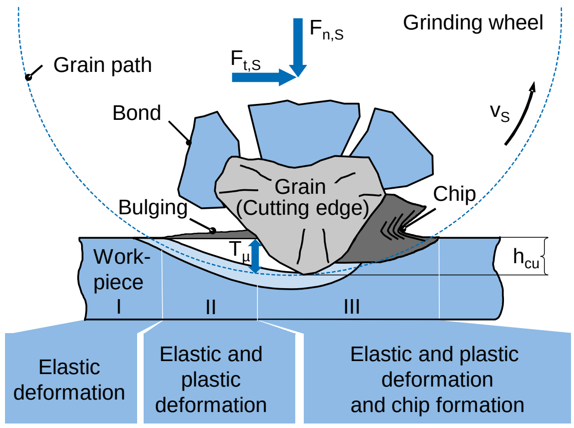

Figure 1: Zones of elastic deformation, plastic deformation and chip formation during grinding [3]

3. Characteristics of High Performance Grinding

High Performance Grinding processes are defined by a significant improvement in comparison to conventional grinding processes of one or more of the four performance characteristics time, cost, quality and feasibility (Figure 2).