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Marcin Gołąbczak
Institute of Machine Tools and Production Engineering
Lodz University of Technology
Łódź, Poland

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Preface

The idea of this monograph is to present a comprehensive scientific study containing the entire cognitive and utilitarian knowledge about superhard grinding wheels with metal bond, methods of assessing their operational properties and methods of shaping their cutting properties in conventional and erosive dressing processes, especially in electrochemical and electrodischarge dressing processes. The monograph presents a multi-sided analysis of research results published in global literature and the results of own research carried out in this area.

Chapter 1 indicates the importance of grinding processes in modern production processes, discusses current trends in the development of innovative grinding processes, the need to implement new grinding wheels, including superhard grinding wheels with a metal bond, and demonstrates the need to improve the methods of dressing superhard grinding wheels.

Chapter 2 covers an extensive characterization of the physical and mechanical properties of abrasives made of superhard materials (SD, CD and cBN), describes the metal bonds of grinding wheels, structure and technology of manufacturing of superhard grinding wheels, their utility values and the systems used for their technical characteristics. Also, the advantages of modern superhard grinding wheels compared to grinding wheels made of conventional abrasive materials are characterized and the areas of their potential use in grinding process are indicated.

Chapter 3 highlights a classification of methods and parameters for direct and indirect assessment of the cutting ability of superhard grinding wheels. The group of parameters for indirect assessment of the cutting ability of grinding wheels includes grinding power, grinding temperature, specific grinding energy consumption, vibrations, acoustic emission, grinding efficiency and the G-ratio index. Among the parameters for direct assessment of the cutting ability of grinding wheels, the following parameters are described: roughness and waviness of the grinded workpiece, stereometric parameters, stresses and microhardness in surface layer, macro- and microwear of the grinding wheel, gumming up of grinding wheels and grinding indicators of testers. Also the exemplary research results are presented regarding the assessment of the cutting ability of superhard grinding wheels based on selected criteria and parameters of their assessment. The presented research results concern the assessment of the degree of gumming up of grinding wheels with grinding products (using the X-ray method), the assessment of the their macro- and microgeometry (using the direct profilography method), the cutting ability of grinding wheels (two-parameter external tester grinding method) and the economic aspects of the evaluation of the electrochemical dressing process of superhard grinding wheels.

Chapter 4 covers the classification of dressing methods of dressing superhard grinding wheels with a metal bond, which distinguishes a group of methods for dressing grinding wheels using mechanical machining processes and a group of erosion dressing methods. Selected dressing methods with mechanical machining for shaping cutting surface of superhard grinding wheels are characterized, including dressing with grinding wheels, abrasive whetstones, grinding of soft steel and crushing with a hard roller. The limited usefulness of mechanical processing methods for shaping superhard grinding wheels is demonstrated. The description and characteristics of erosion dressing methods are presented, including dressing with a high-pressure stream of liquid and abrasive, laser dressing, electrochemical dressing, electrodischarge dressing and hybrid dressing systems for superhard grinding wheels. The functional properties of the presented methods of erosive dressing of superhard grinding wheels are characterized, the advantages and disadvantages of erosive dressing methods are indicated, as well as the areas of their targeted use in the shaping of cutting surface processes of superhard grinding wheels.

Chapter 5 covers the selected results of own research on the electrochemical dressing (ECDGW) and electrodischarge dressing (EDDGW) of superhard grinding wheels, including both mathematical modeling of these dressing processes and experimental research. For the implemented ECDGW process, the theoretical basis for the electrochemical dissolution of gumming up products and components of the metal binder of grinding wheels in this process, as well as mathematical relationships describing the interrelationships between the parameters of the ECDGW process and the results of grinding wheel dressing, are developed. Multilateral electrochemical tests on electrolyte solutions and digestion products produced in the ECDGW process are discussed. Extensive experimental research results of the ECDGW process are also included, confirming compliance with the developed mathematical relationships and shown the effectiveness of the elaborated electrolyte solutions used for dressing of superhard grinding wheels. For the EDDGW process, multilateral experimental tests on dressing of superhard grinding wheels with a strip, rotating and segmental tool-electrode and the effectiveness of these methods of dressing grinding wheels is presented. Also, the research results regarding the possibility of using the hybrid EDDGW and ECDGW system for profiling and sharpening of superhard grinding wheels, using a shaped segmental tool-electrode and electrolytes with a low concentration of chemical compounds are depicted. In this chapter the influence of the inclination angle and feed speed of the segmental tool-electrode and the electrical parameters of the EDDGW electric spark pulse generator on the depth of the shaped profile, the relative wear of the segment electrode and the accuracy of the contour of the profiled grinding wheel are established. Also the mathematical relationships describing the interrelationships between the parameters of the EDDGW profiling process and the wear of the segmental tool-electrode, which enable the design of its dimensions are developed.

The monograph contributes knowledge to the development of machining processes, in particular the improvement of grinding processes and erosion dressing of metal-bonded grinding wheels. It is advisable to continue further research work, aimed at, among others, for development of hybrid dressing systems, including the EDDGW and ECDGW systems, optimization of dressing parameters, improvement of the design of dressing devices, including the innovative segmental tool-electrode, and the issue of eliminating ecological threats, nuisance to the surroundings and the safety of the working environment. The monograph is an important piece of literature, useful both for students of technical universities, university researchers and research and development staff, as well as engineering and technical staff employed in the abrasive tools industry and users of superhard grinding wheels.

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Marcin Gołąbczak

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Contents

Abbreviations

AWJM	Abrasive Water Jet Machining
cBN	Cubic Boron Nitride
CNC	Computer Numerical Control
CPCG	Continuous Path Controlled Grinding
CSGW	Cutting Surface of Grinding Wheel
CVD	Chemical Vapor Deposition
DG	Dry Grinding
ECDGW	Electrochemical Dressing of Grinding Wheel
ECDGW-AC	Electrochemical Dressing of Grinding Wheel Using Alternating Current
EDDGW	Electrodischarge Dressing of Grinding Wheel
EDM	Electrodischarge Machining
EDMD	Electrodischarge and Mechanical Dressing
ELID	Electrolytic In-Process Dressing
GHWGW	Ginder-Holder-Workpiece-Grinding Wheel
HEDG	High Efficiency Deep Grinding
HPHT	High-Pressure High-Temperature
HSG	High Speed Grinding
MRR	Material Remove Rate
ND	Natural Diamond
OPGW	Operational Properties of Grinding Wheel
SD	Synthetic Diamond
SG	Seeded Gel (alumina composite abrasive)—trade name
SGS	Surface Geometrical Structure
SL	Surface Layer
SSG	Speed Stroke Grinding
ST	Surface Texture
TWR	Tool Wear Rate
WEDGW	Wire Electrodischarge Dressing of Grinding Wheel
WJM	Water Jet Machining

Chapter 1
Introduction

Abstract The chapter indicates the role and importance of grinding processes in modern production processes, discusses trends in the development of innovative grinding processes and the implementation of new grinding tools, including: superhard grinding wheels with a metal bond. The development of the operational properties of superhard grinding wheels (OPGW) in dressing processes using conventional and erosion methods is discussed, the content of the monograph is briefly characterized and potential readers to whom the monograph is addressed are indicated.

Keywords Grinding processes · Development trends · Innovations · Superhard grinding wheels · Dressing methods · Erosion dressing

Abrasive grinding still maintains its dominant position among technologies predisposed to efficient and accurate shaping of machine elements, especially those made of difficult-to-machine construction materials. The increase in requirements placed on modern manufacturing processes regarding achieving: high quality machining (including: shape and dimensional accuracy, surface roughness, condition of the surface layer—SL), productivity and flexibility of production and protection of the natural environment, resulted in the improvement of existing and development of new grinding processes [1–3].

Significant progress in the design of grinding machines over recent years, the implementation of numerical control of CNC grinding machines and the mastery of new technologies for abrasive tools have contributed to the creation of a number of innovative grinding processes. The new grinding processes include: high-speed grinding of the grinding wheel—HSG (*High Speed Grinding*) [3–6], high-speed grinding of the workpiece—SSG (*Speed Stroke Grinding*) [4, 7, 8], high-efficiency grinding—HEDG (*High Efficiency Deep Grinding*) [3, 8–10], grinding with reduced contact of the grinding wheel (*Quickpoint*) [11, 12], grinding with continuous control of the grinding wheel path—CPCG (*Continuous Path Controlled Grinding*) [3, 12],

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grinding with minimal cooling—DG (*Dry Grinding*) [13, 14]. Erosive grinding methods are also being developed, including: electrochemical grinding [15, 16], electrodischarge grinding [17–20], hybrid grinding, etc. [21–24].

Great progress has also been made in the development of the design and technology of producing grinding wheels. A significant achievement in this area was the development of new, superhard abrasive and binder materials as well as new grinding wheel designs and technologies for their production. Examples include grinding wheels made of superhard abrasives (such as: natural diamond—CD, synthetic diamond—SD, cubic boron nitride—cBN) bonded with a metal binder [17, 23–26], grinding wheels made of macro- and microcrystalline sintered corundum—SG (*Seeded Gel*) and hybrid grinding wheels [1, 27, 28].

Superhard grinding wheels are characterized by very attractive performance properties. The efficiency of abrasive grinding depends on many input values of the dynamic machining system: grinder, holder, workpiece, grinding wheel—GHWGW. However, the leading role in the GHWGW system is played by the grinding wheel. It carries out the cutting process in the working space of the cutting surface of the grinding wheel—CSGW,[1] using cutting edges shaped on the tops of abrasive grains protruding from the binder. Their operation is similar to the cutting blades of tools used in machining. Significant differences in the structure of grinding wheels, compared to cutting tools with defined blade geometry, significantly limit the possibilities of shaping the operational properties of grinding wheels—OPGW.[2] These limitations apply in particular to shaping the required state of CSGW macro- and microgeometry. Both manufacturers and users of grinding wheels have a direct impact on the shaping of the OPGW.

The scope of possibilities of grinding wheel manufacturers in shaping of the OPGW is determined by the technological process of grinding wheel production, which should ensure repeatability of the parameters of the grinding wheels technical characteristics, such as: shape and dimensions of the grinding wheel, type of abrasive material, dimensions of abrasive grains, hardness of the grinding wheel, binder and structure of the grinding wheel, and in the case of grinding wheels superhard abrasive concentration in the grinding wheel. An extremely important operational requirement for grinding wheel manufacturers is to ensure safe tearing strength of the grinding wheel as well as permissible shape and dimensional deviations and cutting abilities of CSGW, most often achieved by mechanical machining or dressing processes in the final phase of the grinding wheel production process. Users of superhard grinding wheels, however, have the opportunity to shape the OPGW, in particular shaping

[1] The cutting surface of the grinding wheel—CSGW, also called the working surface [29, 30], is the part of the grinding wheel that comes into contact with the grinded object during the grinding process and actively participates in the grinding process.

[2] OPGW—characterizes all the physical features of the grinding wheel relevant to the process and grinding results, determined by: technical characteristics of the grinding wheel, CSGW parameters, technological performance, economic indicators (e.g. price, grinding or dressing costs), etc. [29, 30].

the required state of CSGW macro- and microgeometry during the dressing operation [29, 31, 32]. The operation of dressing of superhard grinding wheels includes three basic procedures: profiling, sharpening and cleaning of the grinding wheel. Grinding wheel profiling[3] is mainly aimed at creating a macrogeometric outline of the grinding wheel's shape profile, which determines the shape and dimensional deviations of the grinded objects. Superhard grinding wheels used for grinding complex CSGW contours are subject to profiling, e.g. grinding wheels for grinding threads, gears, cutting tools. The purpose of sharpening the grinding wheel is to shape the microgeometric structure (topography) of the CSGW, including, among others, the number, shape and arrangement of static and kinematic CSGW blades, which has a fundamental impact on the cutting properties of the grinding wheel as well as the process and grinding results. During this treatment, mainly the binder and blunted abrasive grains are removed, CSGW gluing products are removed and its chip space is increased. Cleaning the grinding wheel (conditioning) is mainly aimed at removing grinding products sticking to CSGW and regenerating cutting abilities.

The role and importance of the above-mentioned dressing procedures in shaping of the OPGW is determined by the strategy of the grinding process, which is to achieve the most favorable technological and economic indicators of this process. Grinding wheel users face two basic problems. The first one concerns the selection of the appropriate dressing method, the selection of dressing tools and dressing parameters, while the second one requires making a rational decision about the advisability of carrying out dressing during the grinding process. Many techniques for dressing grinding wheels are known and used in the literature and industrial practice. They differ in the mechanism of shaping CSGW, the structure of the tools and dressing devices used there, and the scope of their intended use. The most frequently represented group of dressing are "mechanical dressing" methods, e.g. dressing with standing diamond dressers, rotating dressers, hard roller kneading, grinding with grinding wheels and whetstones, grinding of soft steel, etc. [2, 30, 32]. This group of dressing methods is intended mainly for shaping CSGW of grinding wheels made of conventional abrasives such as Al_2O_3 or SiC and, to a limited extent, for dressing grinding wheels made of superhard abrasives bonded with a ceramic or resin binder.

The difficulty of using mechanical methods for dressing superhard grinding wheels with a metal bond results mainly from their specific physical and mechanical properties, including high hardness of the abrasive and the strength of the metal bond. For these reasons, mechanical dressing methods for superhard grinding wheels are ineffective and uneconomical. The specificity of dressing superhard grinding wheels with a metal bond, compared to conventional grinding wheels, is: striving to obtain the required CSGW microgeometry, while minimizing the removed abrasive layer in this process (due to the high cost of superhard grinding wheels), achieving high geometric accuracy of the grinding wheel, eliminating mechanical loads, which adversely affects the intensity level in the structure of the grinding wheel and the

[3] Profiling is also mechanical processing of a newly mounted grinding wheel on the grinding spindle in order to obtain the required shape and dimensions CSGW [30].