ISSN 1063-4576, Journal of Superhard Materials, 2018, Vol. 40, No. 5, pp. 348–354. © Allerton Press, Inc., 2018.
Original Ukrainian Text © V.I. Lavrinenko, 2018, published in Sverkhtverdye Materialy, 2018, Vol. 40, No. 5, pp. 69–78.

INVESTIGATION OF MACHINING PROCESSES

Current Advances in the Development of Abrasive Tools and Investigation of Diamond Abrasive Machining Processes (Materials Science Approach). Review

V. I. Lavrinenko

Bakul Institute for Superhard Materials,
National Academy of Sciences of Ukraine,
vul. Avtozavodska 2, Kyiv, 04074 Ukraine
e-mail: lavrinenko@ism.kiev.ua

Received February 12, 2018

Abstract—The paper reviews the latest advances in the development of abrasive tools and investigation of diamond abrasive machining processes. The review demonstrates the necessity of taking into account the interaction between abrasive and workpiece materials as well as the influence of elements of a workpiece material on wear of abrasive grains; also, it shows the importance of sorting diamond grains by shape, especially within a wide range of their strength. Special features of application of CVD diamonds and the methods for changing the diamond–bond interface zone in order to improve grain retention are discussed.

DOI: 10.3103/S1063457618050064

Keywords: diamond abrasive machining, materials science, diamond, CVD diamond, wheel bond, interaction in the cutting zone.

The present-day changes in the education sector and in the concepts of post-graduate and PhD student tuition demonstrate that greater attention should be paid to the materials science issues during the investigation of machining processes. In the R&D activities aimed at elaborating and implementing tools of superhard materials it is important to have a deep insight into the edge cutting [1] and diamond abrasive machining operations [2]. This paper reviews the advances in this materials-science area made by researchers in this country and abroad over the last decade. Generally, we will discuss the publications where an abrasive and workpiece materials were considered as the main factors that had an influence on the machining process.

Nowadays, abrasive machining in engineering industries is more than just a way of achieving a required workpiece surface roughness—it has become one of the most productive methods of machining various materials. At present, the volume of abrasive operations in the domestic industries accounts for more than 30% of the total volume of metalworking, and in the case of manufacture of bearings the figure exceeds 70%. In the world metalworking practice the total share of abrasive machining is as large as 50% [3]. To make the best use of abrasive wheels, it is a must to take into consideration the abrasive grain size and the wheel hardness. Meanwhile, it is important to keep in mind other properties of an abrasive material as well. Specifically, the grinding ratio for the wheels made of the common fused alumina differs from that for white fused alumina, chromium/titanium- and titanium-doped fused alumina, and monocrystalline alumina by a factor of 0.8, 1.2, and 1.5, respectively; the grinding ratio for black silicon carbide wheels differs more than 0.8-fold from that for green silicon carbide wheels [3].

Esmantovich [4] studied the influence of a workpiece material and a wheel bond material on the process of abrasive machining. In particular, the chemical composition of the workpiece metal has a strong effect on the quality of machining with cutoff wheels, on the chip oxidation rate and machined surface quality. For example, aluminum, silicon, nickel, and other materials are capable of forming a chemically stable film, which improves the oxidation resistance of the alloys. On the contrary, a rise in carbon content reduces the oxidation resistance of the alloys and thus facilitates the formation of chip and its removal from the wheel surface. Increasing the oxidation rate improves the process of cutting, while decreasing it impairs the process [4]. This finding is consistent with the conclusions [2] made during the research performed by Bakul Institute for Superhard Materials of the National Academy of Sciences of Ukraine (hereinafter, ISM).

Esmantovich [4] investigated also the properties of a wheel bond—active fillers. Specifically, in the case of a resinoid bond the chemically active fillers (sulfur and/or halogen vapors) enter the cutting zone and facilitate the cutting of stainless and alloyed steels. For abrasive manufacturers of the European Union a new 3S technology was elaborated, which is based on the use of adaptable fillers and new-generation phenolic resins. As a part of the compound, the fillers regulate the cutting process through a highly endothermic reaction that assists in dissipating heat from the cutting zone.

Implementation of active fillers has initiated one more avenue in the abrasive tool development—the invention of highly porous abrasive tools [5, 6] which are now actively marketed in Ukraine [7]. A significant drawback of such tools is that they are not strong enough. Also, the excessive bond material that encloses the grains reduces the pore size and increases friction in grinding. Kryukov et al. [5] put forward the following actions to overcome these drawbacks: (i) add a finer diamond grain fraction to the main one in order to increase the number of contact points between the grains, and (ii) use an additional pore-forming agent that raises the porosity and, which is equally important, drives out the bond from the grain surface. A similar approach was also proposed in [6] for highly porous cBN wheels. In that case, the abrasive fillers were microcrystalline alumina grains produced by the SG technology (the grains were two orders of magnitude smaller than the cBN grits), while the pore-forming agents were alumosilicate microspheres measuring 5 to 560 μm and particles of crushed fruit pits with a size similar to that of cBN grits. As a result, such wheels can be effectively used for grinding hardened steels without any coolants or with a minimum oil mist cooling.

The aforesaid points to the fact that the grain size is an important input parameter of an abrasive tool. Also, it was noted in [8–10] that one of the factors that impaired the grinding efficiency was the use of arbitrarily shaped abrasive grains in the grinding tools. When this factor is taken into account and an appropriate grain shape sorting is applied, one can achieve a greater effect from the work of each single grain sorted by shape [8]. This was considered in [9], where new methods were used for measuring and describing the diamond particle shape that undertook changes during abrasion. The diamond grain shape along with mechanical properties of the grains constitute an important aspect in the assessment of efficiency of the abrasive machining process. This is particularly important for single-layer diamond tools, where the grain shape has not been affected by the pressing and sintering processes which are usually involved in the manufacture of multilayered diamond tools.

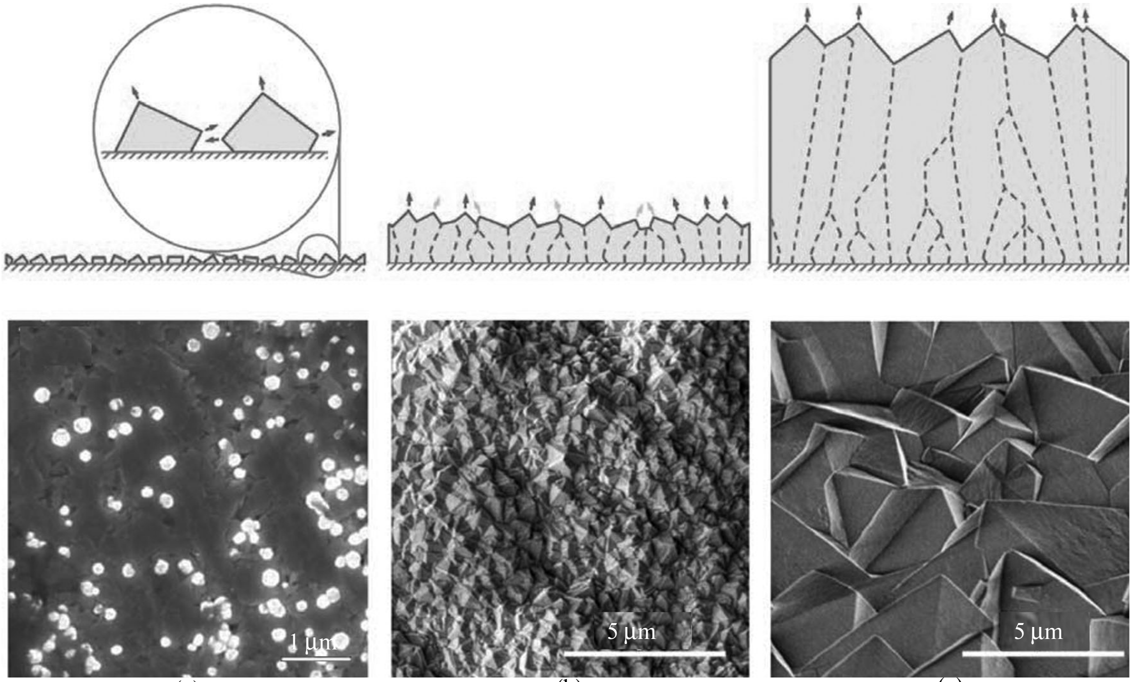
It was also demonstrated in [9] that the size and shape are inseparable notions in the description of the particles whose shape is not clearly defined (i.e., they are not just spherical, or cubic, etc.). The most significant parameters for the diamond grain assessment are the diameter (minimum, mean, and maximum), diameter ratio, convexity, perimeter, and shape accuracy. They provide a basis for a comprehensive characterization of diamond grains and control of their quality. This approach was also extensively applied by ISM in [11] and in [10], where the researchers analyzed the diamond grain shape data for a wide range of grain strength grades (from AC15 to AC100) and discussed the related changes in removal rate in grinding of natural stone samples falling into machinability class 3. It was shown in [10] that with increasing grain strength from AC15 to AC80 the removal rate grew and the grinding ratio for AC80 was 1.88 times that for AC15 (whose ratio was 1.0); then, for AC100 the ratio exhibited almost no rise (1.92), i.e., it was reasonable to assume that the grain shape underwent no significant changes any longer. It would be important to undertake research efforts to assess the above-mentioned characteristics of the diamond grain shape over a wide range of their strength and clarify their behavior within that range, considering that no such information has been found in the relevant publications.

Considerable recent attention has been focused on electrodeposition of composition coatings, especially nickel-containing ones [12–14]. These single-layer tool coatings make it possible to implement a fairly simple method for providing an ordered arrangement of diamond grains [12], a necessary orientation of even partially coated diamonds [13], and producing diamond-containing magnetic abrasives [14]. Therefore, it is advisable to have such coatings made up of diamond particles synthesized by the chemical vapour deposition (CVD) method with different ways of the gas phase activation [15–18]. The benefit of CVD diamonds is that their physical-mechanical properties are close to those of natural diamonds and they have a thermal conductivity of 900 to 1200 W/(m·K) [15]. CVD diamonds can be used in thin coatings (for example, for cutting tools Yoshiko Sato et al. [16] described a process of sharpening a CVD diamond coated tool with the in-process monitoring of the cutting edge condition) and thick coatings (for abrasive tools [17, 18]). Also, the application of CVD diamonds in dressing tools holds much promise [15].

The technology of producing a CVD diamond layer on a grinding tool was described in detail in [17]. This diamond layer can be made up of numerous crystallites and have a thickness from one to a few dozens of microns (Fig. 1).

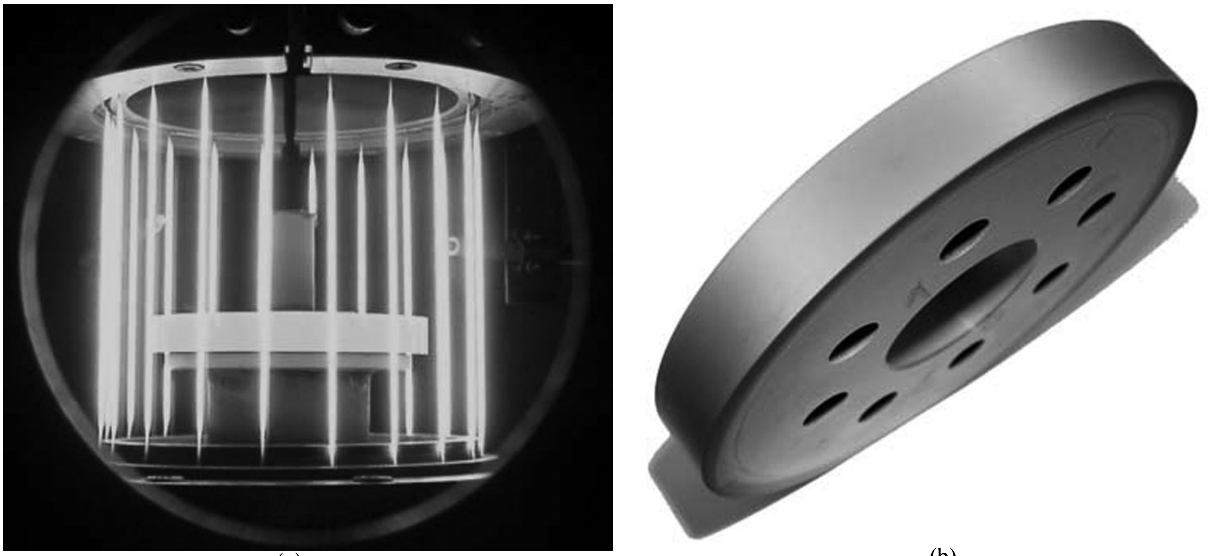
During the chemical vapor deposition the diamond crystals start growing in all directions (Fig. 1a), but when they become large enough to contact each other their further growth proceeds mostly upwards. The surface of this CVD diamond layer is composed of pyramid- or tetrahedron-shaped crystallites (Fig. 1b). Then, some crystallites grow faster than others, become bigger, and the number of crystallites on the surface decreases with increasing thickness of the surface layer (Fig. 1c).

Depending on the holding time, a layer of certain thickness and roughness is formed [17]. The chemical deposition occurs in vacuum chamber with a gas mixture of hydrogen and 0.5–2 wt % methane at a pressure of 100 GPa and gas flow rate of 1 L/min. The gas phase activation was provided through electric heating via tantalum elements. With a tool temperature of about 800°C the deposition lasted for 15–80 hours depending on the tool size and required coating thickness. The tools coated with microcrystalline CVD diamonds measuring 0.5 to 25 μm can be used for precision and ultra-precision grinding of ceramics, hardmetals, and glass. Figure 2 shows a 80-mm-diameter straight grinding wheel during and after the coating deposition. The disk body is made of silicon nitride [17].



(a) (b) (c)

Fig. 1. An CVD diamond layer: onset of growth (a), thin layer (b), and thick layer (c) [17].



(a) (b)

Fig. 2. An 80-mm-diameter CVD-diamond grinding wheel during (a) and after CVD coating application (b) [17].

The publications [12, 13] addressed some issues relating to the diamond grain retention in a bond; this is of great significance for electrodeposited single-layer composites bonds but even more important for high-temperature multilayered metal bonds that have to hold high-strength grains. Similar investigations were also performed in [19], where CrB_2 was added to the system Fe–Cu–Ni–Sn in order to reduce graphitization at the diamond–bond interface and to produce suitable nanostructures, thus improving the diamond grain retention. For the system Fe–Cu–Co–Sn these aspects were studied in [20], where graphite was shown to accumulate at the interface between a diamond grain and the bond (Fig. 3) and impair adhesion between them.

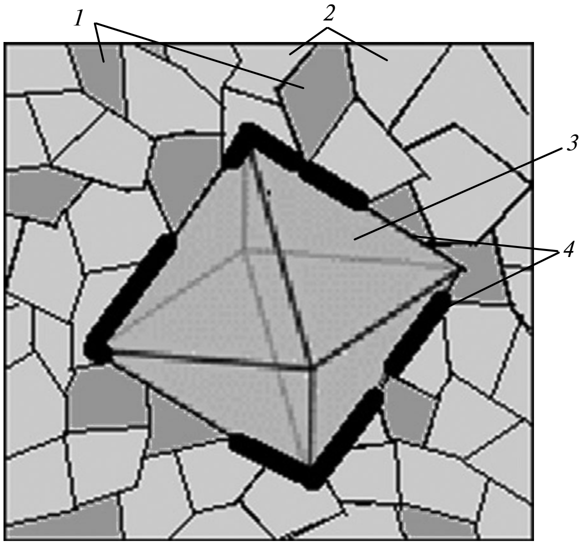


Fig. 3. A schematic representation of diamond graphitization in the wheel bond [20]: *1*—Cu-based phase; *2*—Fe-based phase; *3*—diamond; *4*—graphite.

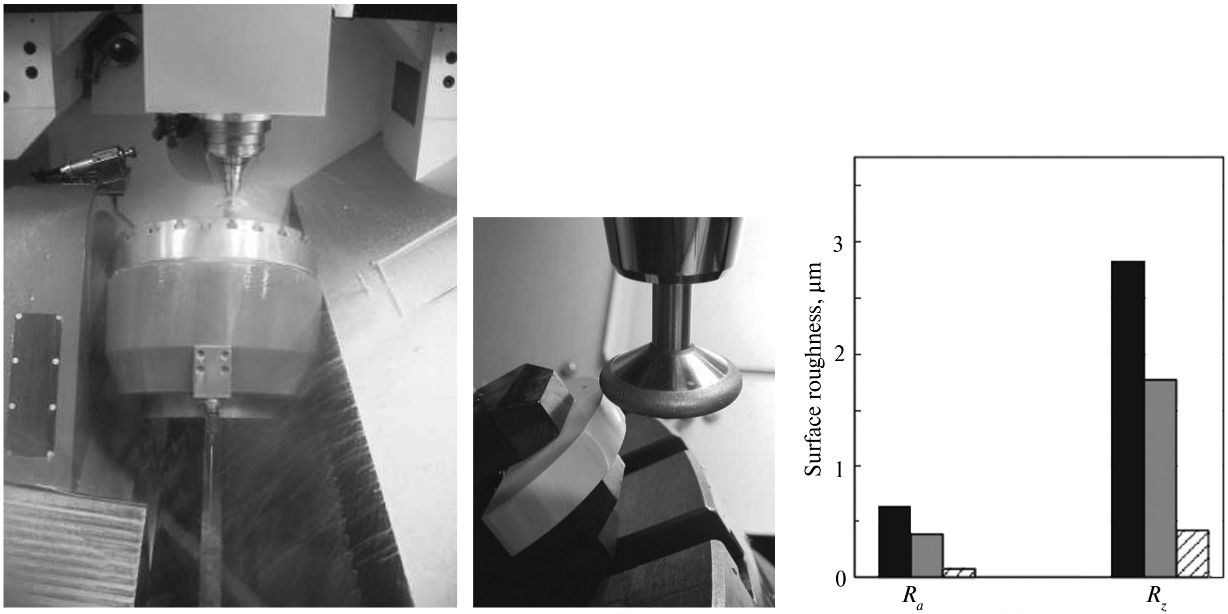
In [20] this problem was investigated by adding nanopowders of Mo, WC, and ZrO_2 to the system Fe–Cu–Co–Sn. It was found out that in the presence of Mo and ZrO_2 nanopowders the process of graphitization becomes more intensive, while the WC nanopowder additive reduces graphitization by 25–30%. Sidorenko et al. [20] attributed the beneficial role of the WC to the enhanced (by up to 70%) blocking of the diamond grain surface, which improved adhesion of the bond to the grain and thus ensured a longer life of the abrasive tools [20].

Let us look at one more important issue: an interaction between a diamond grain and various advanced workpiece materials in microcutting. Earlier, special features of microcutting were studied quite extensively. However, since that time novel materials have emerged, for which the microcutting behavior is still to be clarified. Specifically, the publication [21] provided some findings of the investigation of diamond microcutting of VolKar grade hardmetals containing nanosized tungsten monocarbide particles. It was demonstrated that for these materials the thickness of cut with a diamond grain should be no less than 0.3 μm, because with a smaller thickness the chipping of microedges of a diamond grains becomes much more intensive, i.e., this nanosized workpiece material exhibits a more active resistance to microcutting. Yujie Niu et al. [22] studied a mechanism of microcutting in ultra-precision grinding of monocrystalline silicon. The calculations and experimental results showed that the maximum depth of cutting with a single grain should be within 0.221 μm in order to achieve the plastic cutting mode. It is this mode, which ensured the smallest thickness of the affected (defect-containing) layer in the machined surface of monocrystalline silicon [22]. Kuzei and Lebedev [23] investigated special features of microcutting with a diamond material—synthetic diamond with an increased amount of nitrogen (Almazot grade). They addressed the wear mechanism of this diamond when cutting an abrasive material, namely, an 24A fused alumina grinding wheel. It was demonstrated in [23] that under the conditions of microcutting of an abrasive material it was brittle fracture which was the prevailing mechanism of wear of Almazot crystals (much like in the case of conventional synthetic diamonds). On the other hand, an increase of temperature in the contact zone between Almazot and the abrasive material, the formation of a defect-containing layer on Almazot, and the transfer of the abrasive material bond onto the Almazot crystal surface caused a changeover to the adhesive mechanism. The adhesive interaction (and wear mechanism) between Almazot and the abrasive material manifested itself in the transfer of the abrasive material bond (oxide glass) onto the Almazot crystal surface. Under the high-temperature conditions in the cutting zone, this oxide glass is in the viscoplastic state and, therefore, wets the Almazot surface and interacts with it. As a result, the glass particles which were present in microfissures and voids in the wear land surface altered the wear mechanism of the Almazot crystal under the conditions of its dynamic contact with the abrasive wheel surface [23].

Taking into account the above-mentioned special features of grain wear, emphasis is put on the investigation of the state (topography) of the cutting surface of diamond wheels. In particular, Babenko et al. [24] assessed wear of the working surface of a diamond grinding wheel by examining its 3D topography. They performed topographic measurements and 3D visualization of the wheel working surface prior to and after grinding of hardmetal inserts. The performance of friction surface of tools is known to be functionally related to their bearing (or supporting) surface area; therefore, it was the profile bearing length and the profile bearing length ratio which served as a parameter for characterization of the surface examined [24]. It was recommended in [24] that the wheel surface wear in grinding should be assessed by the parameter *Rpk*, which is responsible for wear of grain tips—a decrease of this parameter points to an increase in wear of the tips. Dobroskok et al. [25] discussed the methodology of constructing a 3D model of relief of a grinding wheel working surface, which would be suitable for analyzing the surface characteristics in the system of morphological analysis of triangulation models (the system had been elaborated by the National Technical University Kharkiv Polytechnic Institute). The model was plotted using a set of images of the working surface zones, which differed in the orientation of the space being examined in the course of the imaging. The main advantage of the proposed method is that it provides the possibility of producing adequate 3D models of grinding wheel surfaces through a fairly easy-to-apply procedure [25]. In [26] the topography of the wheel working surface was modeled mathematically, taking into account the grain trajectory on the basis of the kinematic relation between the wheel and the workpiece. For grits that are arbitrarily distributed over the wheel surface the researchers took into consideration the grain shape, size, orientation, and density of distribution over the wheel surface. It was found out in [26] that the wheel surface topography had an influence on the formation of the workpiece surface topography, and some examples of computation of such a surface were given for the case of ultra-precision grinding of monocrystalline silicon.

Meanwhile, the assessment of topography of the wheel cutting surface should include the fact that not the entire wheel surface is in contact with the workpiece surface; only a portion of it is involved in the process due to undulating form changes on the wheel surface. This incomplete contacting was noted earlier in [27], and the undulating form changes were mentioned in [28]. This is also confirmed by the present-day research [29] revealing the formation of waves on the wheel working surface. What this means is that during the assessment of the working surface topography one should take into account on which part of the wheel surface the zone to be examined is located. In [28] we noted the wave motion over the wheel working surface and the nonuniformity of this motion. This brings about some repeating pattern to the grinding process. The cycling in the renewal of the wheel cutting ability was also mentioned in the recent investigations of changes in the surface roughness parameters [30] and periodic variations of the grain protrusion height and wheel wear resistance [31]. This phenomenon can be used to raise efficiency of grinding of hardmetal workpieces [30] or workpieces of polycrystalline superhard materials [31].

Currently, a new grinding method—the precision form grinding on special grinding tools using fine-grained small-diameter diamond wheels. In the above discussion we mentioned wheels with CVD diamonds which, owing to their properties, are suitable for dry grinding of polycrystalline diamond (PCD) products, namely, a precision radius part of PCD cutting inserts [18]. The publications [32, 33] provided examples of how to apply resin-bond diamond wheels in polishing operations, e.g., multiple-axis machining of implants made of oxide ceramics (Fig. 4) [32].



(a) (b) (c)

Fig. 4. 5-axis diamond machining of oxide ceramic implants: a—grinding process (wheel speed = 30 m/s, depth of cut = 0.02 mm, feed rate = 1000 mm/min, wheel diameter = 30 mm, working radius = 2.5 mm, grain size = 46 μm; bond: electroplated and vitrified); b—polishing process (wheel speed = 6.4 m/s, depth of cut = 0.4 mm, feed rate = 100 mm/min, wheel diameter = 12.2 mm, grain size = 20 μm; bond: resin); c—the implant surface roughness upon grinding with the electroplated wheel (black color), vitrified wheel (gray color), and polishing with the resin-bond wheel (hatched) [32].

The precision grinding of silicon carbide Fresnel lenses is carried out using resin-bond diamond grinding wheels with sharp edge in order to meet the specified requirements. In recent years, Fresnel lenses with their excellent optical indexes have been widely employed in solar cells, IR night vision systems, and medical microdevices. On the other hand, machining them is quite a challenge because of hardness and brittleness of silicon carbide. It is solved by using high-precision grinders and small-diameter resin-bond fine-grained diamond wheels, with a precision truing system (Fig. 5) [33].

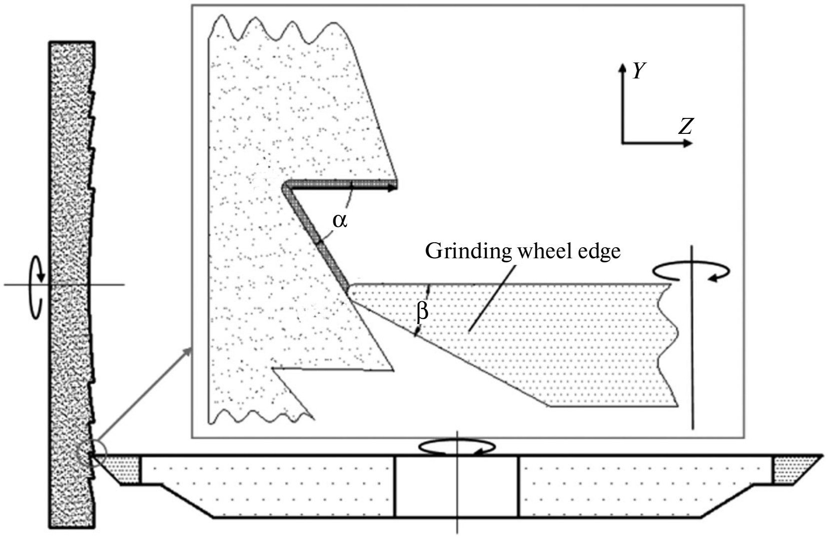


Fig. 5. A schematic representation of grinding a Fresnel lens [33].

We have reviewed here some advances made in the development of diamond tools and in the investigations of diamond abrasive processes taking into account both the diamond grain composition and the bond composition as well as special features of how the grains and bond interact with a workpiece material, i.e., applying the materials science approach to the study of diamond abrasive processes.

REFERENCES

1. Klimenko, S.A., Podchernjaeva, I.A., Beresnev, V.M., Panashenko, V.M., Klimenko, S.An., and Koreikina, M.Yu., AlN–(TiCr)B_2 ion-plasma coating for cutting tools of cBN-based polycrystalline superhard material, *J. Superhard Mater.*, 2014, vol. 36, no. 3, pp. 208–216.
2. Lavrinenko, V.I. and Solod, V.Yu., Oxidation or oxide materials in the machining zone in superabrasive grinding—a factor of influence on the grinding performance, *J. Superhard Mater.*, 2016, vol. 38, no. 6, pp. 417–422.
3. Esmantovich, S.N., Selection of grinding wheel specifications. Optimization of the selection process under factory conditions, *Obor. Instr. Profess.*, 2016, no. 5, pp. 16–19.
4. Esmantovich, S.N., Cutoff wheels. The use of adaptable fillers, *Obor. Instr. Profess.*, 2016, no. 2, pp. 32–38.
5. Kryukov, A.F., Kryukov, S.A., and Gribach, A.E., Innovation-technological support for structural and strength characteristics of high-porosity abrasive tools, in *Mazhdunar. nauchn.-tekhn. konf.* “*Protsessy abrazivnoi obrabotki, abrazivnye instrumenty i materialy. Shlifabraziv-2009”. Sb. statei* (Proc. Int. Sci.-Techn. Conf. Abrasive Machining Processes, Abrasive Tools and Materials), Volgograd: VolgGASU, 2010, pp. 19–21.
6. Starkov, V.G., Highly porous cubic boron nitride wheels for dry grinding, *J. Superhard Mater.*, 2013, vol. 35, no. 5, pp. 298–302.
7. Larshin, V.P., Lishchenko, N.V., Ryabchenko, S.V., et al., Gear grinding using highly porous abrasive wheels of monocrystalline corundum, *Obor. Instr. Profess.*, 2017, no. 2, pp. 26–28.
8. Baidakova, N.V. and Baidakova, T.A., The influence of the abrasive grain shape on the performance of grinding tools, in *Mazhdunar. nauchn.-tekhn. konf.* “*Protsessy abrazivnoi obrabotki, abrazivnye instrumenty i materialy. Shlifabraziv-2009”. Sb. statei* (Proc. Int. Sci.-Techn. Conf. Abrasive Machining Processes, Abrasive Tools and Materials), Volgograd: VolgGASU, 2010, pp. 21–22.
9. De Pellegrin, D.V., Gorbin, N.D., Baldoni, G., and Torrance, A.A., The measurement and description of diamond particle shape in abrasion, in *2nd Int. Industrial Diamond Conf.*, Rome, Italy, 19–20 April, 2007.
10. Peglovskii, V.V., Sidorko, V.I., and Lyakhov, V.N., A study of the dependence of removal rate in grinding of natural stone on the grade of synthetic diamonds in the tool working layer, in *Rezanie i instrument v tekhnologicheskikh systemakh. Mezhd. Nauchn. Tekhn. Sb.* (Cutting and Tools in Technological Systems), Kharkov: NTU “KhPI”, 2011, issue 79, pp. 192–198.
11. Petasyuk, G.A., A system–analogue method of identification of geometric shape of the abrasive grain projection, *J. Superhard Mater.*, 2016, vol. 38, no. 4, pp. 277–287.

12. Ishizuka, H., Sung, J.C., Tsai, M.Y., and Sung, M., PCD pad conditioners for electrolytic chemical mechanical planarization of integrated circuit with nodes of 45 nm and smaller, in *2nd Int. Industrial Diamond Conf.*, Rome, Italy, 19–20 April, 2007.
13. Zhang, Yu, Tani Yasuhiro, Kawahata Yuji, Kirino Okiharu, Proposal of partially ni-coated diamond abrasives for improving grindabilities of diamond tools, in *6th Int. Conf. Asian Society for Precision Engineering and Nanotechnology (ASPEN2015)*, Harbin, China, 15–20 August, 2015.
14. Bin Yang, Wenzhuang Lu, Wei Feng, et al., Adsorption and deposition of micro diamond particles in preparing diamond magnetic abrasives by electroless composite plating, *Diamond Relat. Mater.*, 2017, vol. 73, pp. 137–142.
15. Pyzhov, I.N., Vasil'ev, A.V., and Klimenko, V.G., State of the art and prospects for application of CVD diamonds, in *Rezanie i instrument v tekhnologicheskikh systemakh. Mezhd. Nauchn. Tekhn. Sb.* (Cutting and Tools in Technological Systems), Kharkov: NTU "KhPI", 2011, issue 80, pp. 226–235.
16. Yoshiko Sato, Junki Kawamura, Takashi Nagase, et al., Sharpening of CVD diamond coated tools by 0.5–10 keV Ar^+ ion beam, *Diamond Relat. Mater.*, 2011, vol. 73, no. 7, pp. 954–959.
17. Gabler, J., Pleger, S., and Schafer, L., CVD diamond layers with a controlled roughness enable high-precision and micro grinding tools, in *2nd Int. Industrial Diamond Conf.*, Rome, Italy, 19–20 April, 2007.
18. Takuya Semba, Yoshifumi Amamoto, and Hirokazu Fujiyama, Reactive ion etching of microgrinding tool made of polycrystalline diamond, in *6th Int. Conf. Asian Society for Precision Engineering and Nanotechnology (ASPEN2015)*, Harbin, China, 15–20 August, 2015.
19. Bondarenko, M.O., Mechnik, V.A., and Suprun, M.V., Shrinkage and shrinkage rate behavior in $C_{diamond}$–Fe–Cu–Ni–Sn–CrB_2 system during hot pressing of pressureless-sintered compacts, *J. Superhard Mater.*, 2009, vol. 31, no. 4, pp. 232–240.
20. Sidorenko, D.A., Zaitsev, A.A., Kirichenko, A.N., et al., Interaction of diamond grains with nanosized alloying agents in metal-matrix composites as studied by Raman spectroscopy, *Diamond Relat. Mater.*, 2011, vol. 38, pp. 59–62.
21. Strel'chuk, R.M., Performance of diamond grains in microcutting of hardmetals of nanosized tungsten monocarbide, in *Rezanie i instrument v tekhnologicheskikh systemakh. Mezhd. Nauchn. Tekhn. Sb.* (Cutting and Tools in Technological Systems), Kharkov: NTU "KhPI", 2014, issue 84, pp. 211–214.
22. Yujie Niu, Yifan Dai, Chaoliang Guan, et al., Study on the technology of ultra-precision grinding for aspheric mirror of monocrystalline silicon, in *6th Int. Conf. Asian Society for Precision Engineering and Nanotechnology (ASPEN2015)*, Harbin, China, 15–20 August, 2015.
23. Kuzei, A.M. and Lebedev, V.Ya., Wear mechanisms of Almazot in single-crystal tools during the dressing of grinding wheels, in *Rezanie i instrument v tekhnologicheskikh systemakh. Mezhd. Nauchn. Tekhn. Sb.* (Cutting and Tools in Technological Systems), Kharkov: NTU "KhPI", 2014, issue 84, pp. 145–152.
24. Babenko, E.A., Fadeev, V.A., Fedorovich, V.A., and Fidler, F., Determination of the working surface wear of a diamond grinding wheel by examining its 3D topography, in *Rezanie i instrument v tekhnologicheskikh systemakh. Mezhd. Nauchn. Tekhn. Sb.* (Cutting and Tools in Technological Systems), Kharkov: NTU "KhPI", 2011, issue 80, pp. 15–21.
25. Dobroskok, V.L., Shpil'ka, A.N., and Kotlyarov, V.B., Developing a triangulation model of the working surface relief of grinding wheels, in *Rezanie i instrument v tekhnologicheskikh systemakh. Mezhd. Nauchn. Tekhn. Sb.* (Cutting and Tools in Technological Systems), Kharkov: NTU "KhPI", 2014, issue 84, pp. 85–92.
26. Wang Qiuyan, Liang Zhiqiang, Wang Xibin, et al., Modeling surface topography in ultra-precision grinding process, in *6th Int. Conf. Asian Society for Precision Engineering and Nanotechnology (ASPEN2015)*, Harbin, China, 15–20 August, 2015.
27. Linenko-Mel'nikov, Yu.P., A method of study of the tool–workpiece contact interaction kinetics in grinding, *Sverkhtverdye Materialy*, 1991, no. 6, pp. 40–43 [J. Superhard Mater., 1991, no. 6].
28. Lavrinenko, V.I., The influence of changes in the form of the wheel working surface on the grinding process, *Sverkhtverdye Materialy*, 2000, no. 5, pp. 45–52 [J. Superhard Mater., 2000, no. 5].
29. Kudryavtseva, N.N. and Orlova, T.N., The influence of viscoelastic properties of a modified resin bond on the reduction of intensity of self-excited vibration in grinding, in *Mazhdunar. nauchn.-tekhn. konf.* "*Protsessy abrazivnoi obrabotki, abrazivnye instrumenty i materialy. Shlifabraziv-2009". Sb. statei* (Proc. Int. Sci.-Techn. Conf. Abrasive Machining Processes, Abrasive Tools and Materials), Volgograd: VolgGASU, 2010, pp. 168-171.
30. Ditinenko, S.A. and Kryuk, A.G., Precision diamond abrasive machining of cylindrical hardmetal workpieces, in *Fizychni ta komp'yuterni tekhnologii. Materialy XXIII naukovo-tekhnichonoi konferentsii* (Proc. XXIII Sci.-Techn. Conf. Physical and omputer Technologies), 21–22 December, 2017, Kharkiv, Odessa: ONTU, 2018, pp. 122–129.
31. Grabchenko, A.I., Dyubner, L.G., and Pyzhov, I.N., Improving machining efficiency of polycrystalline superhard materials by making use of the phenomenon of recurrence of the grinding process, in *Rezanie i instrument v tekhnologicheskikh systemakh. Mezhd. Nauchn. Tekhn. Sb.* (Cutting and Tools in Technological Systems), Kharkov: NTU "KhPI", 2011, issue 80, pp. 43–55.
32. Denkena, B., Reichstein, M., and van der Meer, M., Machining ceramic surfaces with adaptable diamond tools for complex implants, in *2nd Int. Industrial Diamond Conf.*, Rome, Italy, 19–20 April, 2007.
33. Yongcheng Pan, Bing Guo, and Qingliang Zhao., Precision grinding of fresnel molds on silicon carbide using resin-bonded diamond grinding wheels with sharp edge, in *6th Int. Conf. Asian Society for Precision Engineering and Nanotechnology (ASPEN2015)*, Harbin, China, 15–20 August, 2015.

Translated by Yu. Kravchenko