https://doi.org/10.15407/scine18.01.056

PASHCHENKO, E. O. (https://orcid.org/0000-0001-5545-5780),
RIABCHENKO, S. V. (https://orcid.org/0000-0002-4599-9810),
Bychykhin, V. M. (https://orcid.org/0000-0003-3147-763X),
Kukharenko, S. A. (https://orcid.org/0000-0001-5256-480X),
Savchenko, D. O. (https://orcid.org/0000-0002-9474-3993),
Kaidash, O. M. (https://orcid.org/0000-0002-8879-3425),
and Smokvyna, V. V. (https://orcid.org/0000-0002-4181-7274)
Bakul Institute for Superhard Materials of the National Academy of Sciences of Ukraine,
2, Avtozavodska str., Kyiv, 04074, Ukraine,
+380 44 430 7694, lab6_1@ukr.net

INNOVATIVE METHOD OF FIXING DIAMOND GRAINS FOR IMPROVING THE PRODUCTION OF DIAMOND-ABRASIVE TOOLS

Introduction. *The single-layer abrasive tool that provides for high machining accuracy, productivity, and ability to control the tool's cutter shape has a potential advantage over other types of abrasive tools.*

Problem Statement. *The tools for high-precision shaping of parts made of high-alloy and heat-resistant steels are the most difficult-to-manufacture, economic attractive, and critically important in the segment. The manufacture of such tools by electrochemical overgrowth of diamond grains with metal on an electrically conductive body is a known technique. However, the traditional manufacture of these tools is associated with significant difficulties and the potential of such diamond products is used only by 15—20%.*

Purpose. *The purpose of this research is to improve the manufacture of high-precision abrasive tools for processing high-alloy and heat-resistant steels at modern machining centers with computer numerical control.*

Materials and Methods. *Electrochemical coating deposition has been made with the use of original method. The obtained coatings microstructure has been studied by the SEM and XRD techniques. The retention strength of diamond grains in a binder has been measured with the use of the designed device.*

Results. *Technology for the manufacture of high-precision single-layer grinding tools by electrochemical metal deposition has been developed. It has been shown that between the steel body and the layer of metal that holds the diamond grains, there is created a thin layer of electrically conductive polymer with a high adhesion to both the body and the metal. This leads to a strong retention of abrasive grains and provides a high degree of grain placement uniformity, which is currently unattainable for the conventional technologies, as well as increases the stability of the sharp edges of the cutter as the most exposed tool parts.*

Conclusions. *For the first time, a new class of high-precision profile tools has been created and tested. It allows the substitution of import at machine-building enterprises of Ukraine and gives access to foreign markets.*

Keywords: precision diamond-abrasive tools, grinding, and electrochemical metal deposition.

Citation: Pashchenko, E. O., Riabchenko, S. V., Bychykhin, V. M., Kukharenko, S. A., Savchenko, D. O., Kaidash, O. M., and Smokvyna, V. V. (2022). Innovative Method of Fixing Diamond Grains for Improving the Production of Diamond-Abrasive Tools. *Sci. innov.*, 18(1), 56—65. https://doi.org/10.15407/scine18.01.056

Grinding processes with the use of various abrasive tools play an important role in the modern manufacture of machine parts. The cutting elements of these tools are hard and heat-resistant grains of abrasive material with sharp edges. There are natural and artificial abrasive materials. The natural abrasive materials include minerals such as emery, quartz, corundum, etc., but they have a large heterogeneity and impurities, so the quality of abrasive properties does not meet the needs of industry. Currently, the artificial abrasive materials have been mainly used in mechanical engineering. The most common artificial abrasives are electrocorundum, silicon and boron carbides. A special group of artificial abrasives is represented by synthetic diamonds and cubic boron nitride (cBN). The use of these superhard synthetic materials has a significant influence on engineering technology and opens up the prospects for the replacement of turning and milling with grinding, in many cases. The main physical and mechanical properties of abrasive materials used in the manufacture of grinding tools are compared in Table 1 [1].

The manufacture of parts with strict requirements for the accuracy and quality of their work surfaces is associated with the difficulty of using the conventional methods of finishing, in particular, grinding as the most common method of abrasive machining. To date, grinding in many cases is the only method of efficient machining of parts made of hardened steels and alloys, hard alloys, heat-resistant and titanium steels and alloys, nonmetallic materials, including hard ceramics, glass, quartz, ruby, sapphire, ferrite, and other hard-to-process materials and may be used in toolmaking, aircraft or turbo-building and other fields of mechanical engineering. Technological capabilities of grinding are extremely great: effective removal of excess metal and ensuring of a high accuracy and quality of machined surfaces are achieved by removing small chips with a large number of cutting edges of abrasive grains within a wide range of cutting speeds. Many of these opportunities have not yet become widespread in industry, and some of them are still potential, insufficiently substantiated and tested. The estimates have shown that a simultaneous increase in the cutting speed (over 100 m/s) and in the thickness of the chips cut by each abrasive grain (2—4 times) allows raising ten times the productivity of material removal in the course of grinding and making it competitive with blade machining. This means that grinding may replace previous machining methods (milling, turning, etc.) and thus reduce the technological cycle of parts manufacture. This statement of the problem may be defined as ultimate goal in the development of new abrasive compo-

Table 1. **Basic Physical and Mechanical Properties of Abrasive Materialss**

Abrasive materials	Microhardness, GPa	Density, g/cm^3	Abrasive capacity	Bulk density, g/cm^3	Heat resistance, °C
Boron carbide	40—45	2.5	0.50—0.60	1.04	700—800
Silicon carbide green	33—36	3.2	0.45	1.48	1300—1400
Silicon carbide black	33—36	3.2	0.40	1.48	1300—1400
Electrocorundum:					
Normal	19—20	3.9	0.145	1.76	1700—1800
White	20—21	3.95	0.156	1.73	1700—1800
Chromic	20—22	3.95	0.101	1.77	1700—1800
Titanium	22—23	3.95	0.112	1.70	1700—1800
Zirconium	23—24	4.10	0.110	1.90	1900—2000
Monocorundum	23—24	3.97	0.150	1.99	1700—1800
Dimond	100	3.49—3.54	1.00	—	800
cBN	92.5	3.44—3.49	0.58—0.60	—	1400

sites and tools. The most important prerequisites for achieving this goal are to increase the stability of the tool, to reach maximum uniformity of its wear and to ensure reliable control the uniformity and, in general, of the geometric parameters of the statistical ensemble of cutting grains.

Successful application of this approach in the future may lead to qualitative changes in the efficiency of the metalworking operations (grooving, notching in solid metal, machining of bearing rings, chip grooves in cutting tools, and so on) that are the most important for mechanical engineering.

In terms of combined capabilities, due to high-precision machining, high productivity and controllability of the shape of the tool cutting profile of the tool, given the modern approaches to the manufacture of precision bodies of any shape, the single-layer abrasive tool has the potential advantage over other types of abrasive tools.

Two types of limitations have a significant unfavorable effect on the realization of the capacity of single-layer tools made by conventional electroplating technology. One of them is related to the uneven wear of the forming tools that have sections of the profile with a small radius of curvature, such as thin edges. Accelerated wear in such areas leads to early decommissioning of high-value tools. The main reason for this phenomenon is high stresses at the interface between the deposited layer of metal and the tool body. The second limitation is a rapid increase in the number and depth of defects on the surface machined, which is associated with increased productivity of machining.

The number and depth of defect penetration into the surface layer of the workpiece is determined by the conditions of contact interaction with the ensemble of abrasive grains on the working surface of the tool. In turn, the dynamics and force parameters of such interaction depend on the uniformity of grain distribution. On the surface of tools, including those of the highest quality, made with the use of conventional principles, the distribution is significantly uneven. On the working surface of such tools the areas without abrasive elements alternate with the areas where abrasive grains are closely aggregated. When the latter contacts with the surface of the part, the temperature and cutting forces hike. This, in turn, leads to the formation of deep, unevenly distributed defects and unevenly distributed roughness on the machined surface.

To avoid such limitations, the best foreign manufacturers resort to costly technological techniques. Among them there are the manufacture of special profile anodes for each small batch and each tool size, the use of ultrapure reagents, the continuous monitoring of purity and composition of the electrolyte with its constant adjustment, the adaptive adjustment of electrochemical deposition of metal to changes in the microgeometry of the deposited layer. These measures give a partial technical effect in terms of tool stability and insignificantly contribute to the reduction of defects in high-performance grinding.

The ineffectiveness of these techniques is associated with the physical nature of the conventional technological principles of manufacturing abrasive tools by electroplating. According to these principles, firstly, the diamond grains are fixed at the points of the body's contact with the particles from freely spread powder layer, and secondly, the metal that holds the grains is deposited directly on the surface of the metal (usually steel) body. Accordingly, the stresses associated with the "body-deposited binder" are formed between the two layers that have a close modulus of elasticity and are connected only by the adhesion forces of intermolecular nature. This combination of factors significantly increases the risk of stratification, with the areas that have a small radius of curvature being particularly prone to defects.

However, even with the programmable distribution of grains on the surface of the body of a high-precision abrasive tool, which is an extremely time-consuming operation, it is impossible to avoid the formation of long tracks without diamond particles on the cutting layer. This causes fluctuations in the cutting forces, which are repeated cyclically. In the case of the resonance of such cyclic rapid fluctuations with the natural oscillations of the high-precision abrasive or trueing tool and the abrasive product machined, the total vibration in the working area is significantly enhanced. The result is accelerated wear of high-precision abrasive or trueing tools, deterioration of the microgeometry of the cutting surface of the abrasive wheel and the accuracy of its profile. Thus, the stochastic nature of the cutting edges orientation of diamond powder grains, even the high-strength isometric fractions, puts fundamental limitations on improving the accuracy of abrasive wheels and, ultimately, the accuracy of products obtained with the use of abrasive tools.

The obvious approach to solving this problem is to qualitatively improve the homogeneity of diamond grains on the tool surface during grinding, which leads to a significant increase in the number of abrasive grains involved in removing the excessive metal, as well as to an improvement in the properties of trap finished surfaces [2—4].

The authors have chosen to improve the manufacture of high-precision abrasive tools for machining high-alloy and heat-resistant steels in modern machining centers with numerical programmable control.

The manufacture of high-precision abrasive tools may be divided into the three main stages:

1) a film of viscous binder — aniline-based oligomer — is applied by the electrochemical method to the metal (steel) surface of the tool body treated with organic reagents. The steel substrate serves as an electrode that is immersed in an acidic solution of aniline. Based on previous experience in obtaining such coatings, the concentration of aniline is 1 mol/dm^3 and the concentration of sulfuric acid to increase the acidity is 0.3 mol/dm^3. The voltage in the course of the film deposition is 1 V, and the current density is 0.2 A. The duration of the substrate film formation and thickening ranges from 1 to 6 days.

2) abrasive grains are applied to a layer of viscous binder from an aqueous suspension in a fluidized bed of powders of superhard materials (diamonds or cubic boron nitride). Further, the binder is polymerized by heat treatment at a temperature of 130—140 °C for 15—120 min, depending on the weight of the metal base.

3) finally, the abrasive layer of the tool is formed by electrochemical deposition of a metal binder (Ni, Co, Cu, Fe) on the surface of the conductive polymer.

The electrochemical deposition of coatings has been made with the use of the original method developed at the Bakul Institute for Superhard Materials of the NAS of Ukraine. To work out efficient techniques for coating the surface of the tool bodies, the formation of coatings on asymmetric sinusoidal current of industrial frequency under external magnetic field (MF) with adjustable duration of exposure in the specified direction on the deposition surface has been studied. The electric formation of the coating on the reverse current of industrial frequency in the absence and under the influence of external magnetic field the direction and duration of which on the deposition surface may be adjusted has been made with the use of a special device designed at the Bakul ISM of the NAS of Ukraine [5]. Typically, to establish modes of non-stationary electrolysis, a system of parameters, which is convenient for quantifying the deposition of coatings and provides the ability to compare their physical and mechanical properties with the properties of metals formed under direct current, is chosen [6]. The asymmetry coefficient β is used as a generally accepted parameter to characterize the asymmetric reverse current.

The experiments to determine the strength of diamond grains in the binder under static load have been carried out according to the method [7], with the use of the device for measuring the strength of abrasive grains in the binder, which is designed at the Bakul ISM of the NAS of Ukraine [8].

The microstructure of the obtained coatings has been studied with the help of the scanning electron microscopy (*Carl Zeiss EVO 50*, Germany) and the *X*-ray diffractometry (*DRON*-1.5) methods.

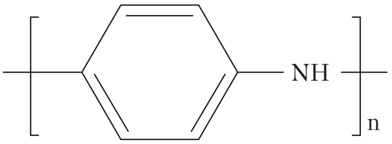

Fig. 1. Chemical formula of polyaniline

A new approach to the manufacture of high-precision single-layer grinding tools by electrochemical deposition of metal has been developed at Bakul Institute for Superhard Materials of the NAS of Ukraine. This approach that allows overcoming or significantly reducing the above-mentioned limitations of the effective use of the tool is based on the following new technological principles:

1 — grains from an aqueous suspension are fixed on the body, on a layer of viscous binder capable of further polymerization with the formation of an electrically conductive polymer;

2 — electrochemical deposition occurs on the surface of an electrically conductive polymer that contains functional groups capable of chemical bonding of primary metal clusters.

The mechanisms of electrical conductivity of metal differ significantly from the mechanism of electron motion in polymers. Therefore, even with a high electrical conductivity of the polymer, there may be a potential barrier on the polymer-metal interface, which at the macroscopic level may manifest itself in the formation of mechanical stresses and undesirable electrophysical phenomena both in the course of the formation of the diamond-bearing layer of the tool and in the course of its tool operation. In order to convert the technological advantages of the new principles of tool's diamond-bearing layer formation by electrochemical deposition of metal, it is necessary to apply approaches that minimize the above mentioned potential barrier due to the different physical nature of the polymer films and the tool's steel body. Our research has shown that this may be achieved by providing intensive injection[1] of charge carriers (mainly electrons) from the conductive body to the polymer film.

Table 2. **The Properties of Polyaniline Coating Depending on Polymerization Time**

Time, days	Thickness of coating, μm	Force to pull out diamond grains AC160 500/400 at static loading, N
1	56.5	0.1
2	66.0	2.3
4	72.5	1.4
6	76.5	0.5

Electrically conductive films of polyaniline polymer (Fig. 1) on steel substrates have been formed with the use of the electrochemical method. The thickness of the coatings obtained at different times are given in Table 2.

Further, the obtained films are coated with grains of diamond or cubic boron nitride by immersing a metal base coated with a layer of aniline oligomer in a fluidized bed of powders of superhard materials. That is, the grains from an aqueous suspension are fixed on a layer of viscous binder capable of further polymerization with the formation of an electrically conductive polymer, on the metal body. Finally, the abrasive layer of the tool is formed by electrochemical deposition of a metal binder. The metal is electromechanically deposited on the surface of an electrically conductive polymer containing functional groups capable of chemical bonding of primary metal clusters [9].

As a result of this approach, a thin (several micrometers) layer of electrically conductive polymer is formed between the steel body and the deposited layer of metal containing diamond grains. This polymer layer has a high adhesion to both the body and the deposited metal. As compared with the discharge directly on the surface of steel, the discharge of metal ions on the surface of such a polymer forms a layer of metal of uniform thickness, which is much less dependent on the curvature of the surface. The presence of a strong and adhesive, but less rigid, layer of polymer between

---

[1] Injection in semiconductor engineering means the transition of charge carriers through an electron-hole junction junction with further recombination to the semiconductor area where these charge carriers are minor ones.

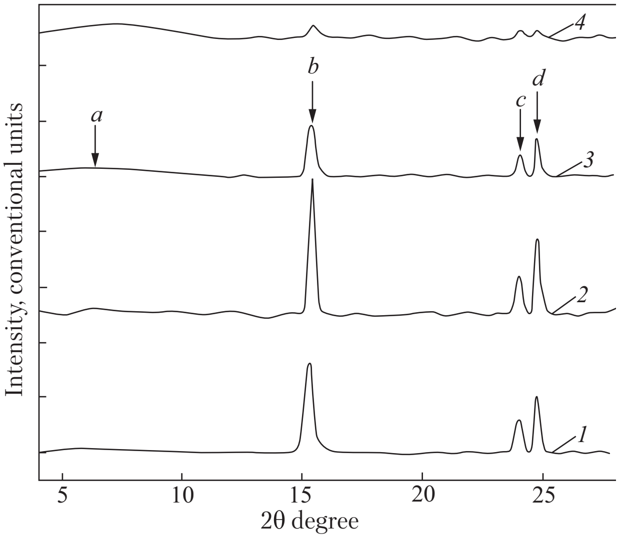

Fig. 2. Diffractograms of polyaniline films obtained by the electrochemical method, of different thickness: 56.5 μm (*1*); 66.0 μm (*2*); 72.5 μm (*3*); and 76.5 μm (*4*). The interpretation of the letters is given in the text

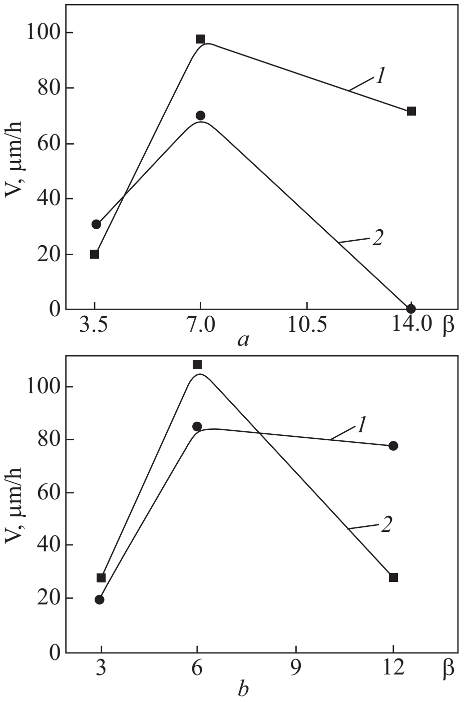

Fig. 3. Nickel deposition rate depending on the asymmetry coefficient β at the average density of asymmetric anode current 0.4 A/dm^2 (*a*) and 0.8 A/dm^2 (*b*): at an asymmetric sinusoidal current (curve *1*); at an asymmetric sinusoidal current in a magnetic field (curve *2*)

the body and the layer of metal binder contributes to the effective relaxation of stresses and significantly reduces the risk of fatigue failure of the most dangerous areas on the tool's thin edges. It is also important that the pre-fixing of diamonds on the tool body on the layer of viscous oligomeric composition creates a high uniformity of distribution of diamond grains on the surface of the metal body. This enables reducing the probability of defects of machined surfaces while keeping a high productivity of grinding with variable feed rates and a high speed of rotation of the tool on numerically programmable machines.

To establish the most optimal thickness of the polymer coating, the force of pulling out a previously fixed abrasive grain has been measured. These factors (coating thickness, pulling force, see Table 2) are interconnected because of the orderliness and crystallinity degree of the produced polymer [10, 11], which is confirmed by *X*-ray phase analysis of the obtained films (Fig. 2):

In Fig. 2, halo (*a*) characterizes the presence of the amorphous component of the obtained polymer, and peaks (*b*), (*c*), (*d*) correspond to the formation of crystalline planes. A decrease in the area under peaks (*b*), (*c*), (*d*) and an increase under the halo (*a*), as the coating thickness grows, indicates the amorphization of its structure. In our opinion [12], such a change in the area under the peaks means a decrease in the coating orderliness, which in turn leads to a decrease in charge transfer in such films. As a result, in these areas, during electrochemical deposition of metal, its growth slows down and the metal itself has a flaky structure with less adhesion to the diamond grain that under the action of external load is more easily separated from the metal layer. Given the results obtained (Table 2, Fig. 2), it has been found that 66 μm thick coating has the optimal properties. Polyaniline-based coating of this thickness is the starting point for further experiments.

The study on the final formation of a metal coating by electrochemical deposition of a metal binder has shown the dependence of changing

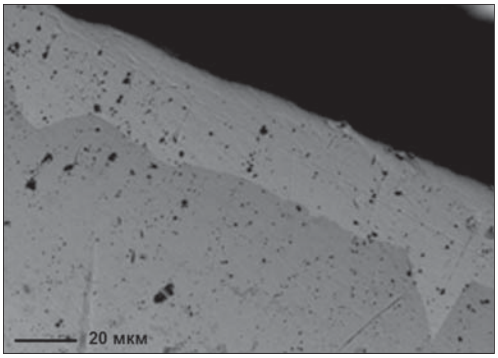

Fig. 4. Image of a cross section. The structure of nickel coating formed under the influence of an external magnetic field at an asymmetric sinusoidal current of 0.8 A/dm^2

deposition rate of nickel on the asymmetry coefficient β at average density of asymmetric anode current $i_{\text{a av.}}$ = 0.4 A/dm^2 (Fig. 3, *a*) and i$_{\text{a av.}}$ = = 0.8 A / dm^2 (Fig. 3, *b*). The average density of the asymmetric cathode current is kept constant.

Under the action of a magnetic field on the cathode surface at an average density of asymmetric anode current $i_{\text{a av.}}$ = 0.4 A/dm^2 for different β (Fig. 3, *a*), the intensity of deposition of the electrolytic metal layer is less than in the case of electrolysis on reverse current. If deposits are formed in a magnetic field for β = 6 and $i_{\text{a av.}}$ = = 0.8 A/dm^2 (Fig. 3, *b*), their growth rate reaches a maximum of 100–110 μm/h. In the image of the metallographic section (Fig. 4), the tendency to a deeper penetration of nickel (light gray layer, on the right), as compared with the reverse current mode, into the steel base material is clearly visible. The thickness of the nickel layer penetrating to the depth from the surface of the steel sample may reach 40—50% of the total coating thickness.

Therefore, the processes of nickel electrodeposition at an asymmetric sinusoidal alternating current in the absence and under the action of magnetic field depend mainly on the combination and the value of average asymmetric current density in the cathode and anode half-cycles. The optimal modes of deposition of composite diamond-nickel coatings should provide a combination of individual favorable qualities of coatings, which are typical for nickel deposits, formed for a particular mode of non-stationary electrolysis.

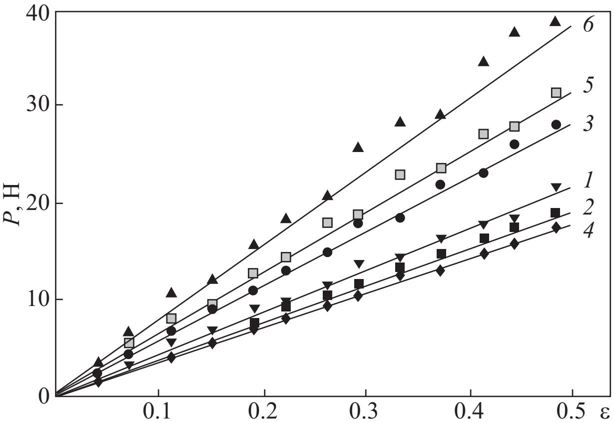

Fig. 5. Dependence of pulling force *P* that acts on diamond grains AC160 500/400 under static load on the relative depth of their fixation ε in nickel electrolytic bond formed at a direct current *i* = 1.0 A/dm^2 (*1*); *i* = 2.0 A/dm^2 (*2*); at an asymmetric alternating current with a frequency of 50 Hz: at $i_{\text{av.}}$ = 1.6 A/dm^2, β = 5 (*3*); at $i_{\text{av.}}$ = 2 A/dm^2, β = 6 (*4*); at an asymmetric alternating current with a frequency of 50 Hz in a magnetic field: at $i_{\text{av.}}$ = 1.6 A/dm^2, β = 5 (*5*); at $i_{\text{av.}}$ = 2 A/dm^2, β = 6 (*6*)

The results of studying the dependence of the diamond retention strength under static load on the relative depth of fixation of AC160 500/400 diamond grains in galvanic nickel layers obtained under different conditions (direct current, asymmetric alternating current in the absence and under the action of external magnetic field, reverse operating current densities optimal for the formation of diamond-galvanic nickel coatings) are shown in Fig. 5.

In Fig. 5, linear dependences 1 and 2 confirm that increasing the operating density of the cathode current leads to a decrease in the angle of inclination of the line. The obtained results are consistent with data [5]. A decrease in the angle of inclination of the line, as the average asymmetric current density increases, has been reported for the bonds formed in modes 3, 4 (Fig. 5, lines *3, 4*). For the coatings formed at an asymmetric sinusoidal current of industrial frequency under the influence of magnetic field as an additional technological parameter, this rule does not work. For modes 5, 6 with a magnetic field (Fig. 5, lines *5, 6*), the angles of inclination of the lines under static load, which reflect the dependence of the pulling force *P* acting on diamond grains on their relative depth of fixation ε, increase, as the average reverse current density grows, and reach maximum, as compared with other modes. Thus, the coatings formed in a magnetic field have a greater adhesion to the surface as compared with the coatings formed at an asymmetric current. This property should be used for applying a sublayer of electrolytic deposit to improve the adhesion of the diamond-bearing coating to the base material of the tool. Fixing the superhard abrasive particles on the surface of the body coated with a film of electrically conductive polymer with high adhesion to steel (the body material) and to the metal binder deposited by electrochemical method provides a significantly stronger retention of abrasive grains. This contributes to a high degree of grain distribution, which is unattainable for the conventional technologies, as well as increases the stability of the sharp edges of the profile, which are the most vulnerable parts of the tool.

The qualitative increase in the uniformity of the distribution of diamond grains on the tool surface in the course of grinding results in a significant increase in the number of abrasive grains involved in the removal of excessive metal, as well as in improved properties of ground surfaces. Grinding plastic metals (steels and alloys) with the formation of an even-height ensemble of evenly spaced grains is associated with following phenomena:

- When chips are formed, the adiabatic shear process starts to prevail. It is accompanied with the localization of the deformation zone and pronounced shear elements with a thickness of 1—5 μm and corresponding fluctuations in the cutting force. The formation of numerous shear zones with a thickness less than a micrometer creates favorable conditions for chip removal through reducing the shear resistance. Increasing the cut thickness by one abrasive grain also contributes to the formation of elemental chips.
- The maximum thickness of the slice increases. The abrasive grain endures this increase, which allows increasing the volume of a single slice several times. This sharply reduces the sliding path of the grain and the separation of chips starts earlier. So, the percentage of grain tops that perform the work of elastoplastic deformation of the metal without separation of chips decreases. The deformation zone and lappings on the sides of the grinding lines significantly decrease (the coefficient of extrusion of the metal is reduced about 3 times for machining hardened steels). These phenomena indicate a great potential for the intensification of metal removal in the implementation of the described approach.
- The results of studying the chip surfaces and grinding lines with the use of a scanning electron microscope have shown the possibility of a “cleaner” cut (especially for cutting grains of cubic boron nitride) with reduced lapping, flaking, fiber breaking, and other traces of plastic deformation and promotes the creation of finished surface with improved quality parameters.

At the Zaporizhzhia Engineering Design Bureau *Ivchenko Progress,* a special high-precision abrasive tool for machining high-alloy and heat-resistant steels at modern numerically programmable machining centers has been tested. The presented grinding tools are competitive with similar tools from *Tirolyt* (Austria) and *Molemab* (Italy) in terms of wear resistance and cutting force parameters and meet the production requirements of *Ivchenko-Progress* Bureau.

Conclusions

1. With the use of new technological principles, the Bakul Institute for Superhard Materials of the NAS of Ukraine has developed a technology for manufacturing high-precision single-layer diamond profile tools of various sizes for grinding critical parts made of heat-resistant and high-alloy steels at machine-building enterprises of Ukraine. This new class of high-precision profile tools has never been designed or manufactured in Ukraine. However, it has been widely used at machi-

ne-building corporations of Ukraine for the manufacture of a wide range of parts at numerically programmable machining centers.

2. It has been shown that fixing superhard abrasive particles on the surface of tool's body by a film of electrically conductive polymer with a high adhesion to steel (body's material) and to metal binder deposited by electrochemical method ensures a strong retention of abrasive grains. This provides a high uniformity of grain distribution, which is unattainable for the conventional technologies, and stability of the sharp edges as the most vulnerable parts of the tool.

3. The tests of special high-precision abrasive tool for processing high-alloy and heat-resistant steels at modern numerically programmable machining centers. The presented grinding tools are competitive with foreign analogs in terms of wear resistance and cutting force parameters and meet the production requirements of *Ivchenko-Progress* Bureau.

4. Industrial application of the obtained research results allows domestic machine-building enterprises to reach a new level of technological readiness in creating competitive diamond and profile tools for grinding the critical parts made of heat-resistant and high-alloy steels, as well as to decrease the expenses on importing critical tools, and to reduce the dependence on foreign suppliers.

REFERENCES

1. Riabchenko, S. V., Sereda, G. V., Valuyskiy, V. Yu. (2017). Grinding of gear wheels with ruby-corundum abrasive wheels. *Equipment and tools for professionals. Metalworking series,* 5, 48—51 [in Russian].
2. Pashchenko, Y. O., Sokhan', S. V., Sorochenko, G. V., Savchenko, D. A., ..., Mikishchenko, O. A. (2020). Effect of the tool composite porosity on the efficiency of profile diamond grinding of sapphire and zirconium dioxide. *J. Superhard Mater.,* 42(4), 264—275. https://doi.org/10.3103/S1063457620040073.
3. Kovalchenko, A. M., Goel, S., Zakiev, I. M., Pashchenko, E. A., Al-Sayegh, R. (2019). Suppressing scratch-induced brittle fracture in silicon by geometric design modification of the abrasive grits. *Journal of Materials Research and Technology*, 8(1), 703—712. https://doi.org/10.1016/j.jmrt.2018.05.016.
4. Pashchenko, Ye. A., Bychykhin, V. N., Savchenko, D. A., Kukharenko, S. A., ..., Virchenko, V. S. (2019). Diamond grinding wheels on new siloxane binders, microwave-cured. *Equipment and tools for professionals. Metalworking series*, 6, 66—68 [in Russian].
5. Prudnikov, Ye. L. (1985). *Diamond electroplated tool.* Moscow: Mechanical Engineering [in Russian].
6. Bibikov, N. N. (1961). *Deposition of metals on alternating polarity current.* Moscow: SSTI "Mashgiz" [in Russian].
7. *Patent of Ukraine No. 32598.* Konovalov, V. O., Shatokhin, V. V. A method of measuring the holding strength of abrasive grains in the binder of an abrasive tool [in Ukrainian].
8. *Patent of Ukraine No. 32367.* Konovalov, V. O., Shatokhin, V. V., Kuz menko, Ye. F., Staryk, S. P. Device for measuring the strength of abrasive grains in the binder [in Ukrainian].
9. *Patent of Ukraine No. 143407.* Pashchenko, Ye. O., Bychykhin, V. M., Kukharenko, S. A., Savchenko, D. O., Filatov, Yu. D., Riabchenko, S. V., Kaidash, O. M, Smokvyna, V. V., Schur, N. A. A method of manufacturing a high-precision abrasive tool [in Ukrainian].
10. Du, X., Xu, Y., Xiong, L., Bai, Y., Zhu, J., Mao S. (2014). Polyaniline with high crystallinity degree: Synthesis, structure, and electrochemical properties. *J. Applied Polymer Science*, 131(19), 40827. https://doi.org/10.1002/app.40827.
11. Chen, P. Y., Hung, H. L., Han, C. C., Chiu, H. C. (2020). Correlation between nanoscale elasticity, semiconductivity, and structural order in functionalized polyaniline thin films. *Langmuir*, 36(15), 4153—4164. https://doi.org/10.1021/acs.langmuir.0c00100
12. Pashchenko, E., Savchenko, D., Kaidash, O., Kukharenko, S., Rumiantseva, Y., Buriachek, O. (2020, November). Synthesis of Hybrid Partially Oxidized Nanodispersed Metal Particles with Simultaneous Surface Functionalization *Proceedings 2020 IEEE 10th Intern. Confer. "Nanomaterials: Applications & Properties" (NAP-2020), (November 09—13, 2020. Sumy, Ukraine)*. Sumy. 01NSSA04-1—01NSSA04-4 p. https://doi.org/10.1109/NAP51477.2020.9309599

Received 09.03.2021
Revised 18.07.2021
Accepted 02.08.2021

Є.О. Пащенко (https://orcid.org/0000-0001-5545-5780),
С.В. Рябченко (https://orcid.org/0000-0002-4599-9810),
В.М. Бичихін (https://orcid.org/0000-0003-3147-763X),
С.А. Кухаренко (https://orcid.org/0000-0001-5256-480X),
Д.О. Савченко (https://orcid.org/0000-0002-9474-3993),
О.М. Кайдаш (https://orcid.org/0000-0002-8879-3425),
В.В. Смоквина (https://orcid.org/0000-0002-4181-7274)
Інститут надтвердих матеріалів ім. В.М. Бакуля НАН України,
вул. Автозаводська, 2, Київ, 04074, Україна,
+380 44 430 7694, lab6_1@ukr.net

ІННОВАЦІЙНИЙ МЕТОД ЗАКРІПЛЕННЯ АЛМАЗНИХ ЗЕРЕН ДЛЯ УДОСКОНАЛЕННЯ ВИРОБНИЦТВА АЛМАЗНО-АБРАЗИВНИХ ІНСТРУМЕНТІВ

Вступ. За поєднанням високої точності обробки, продуктивності та можливості керування формою ріжучого профілю інструменту одношаровий абразивний інструмент має потенційну перевагу над іншими типами абразивних інструментів.

Проблематика. Інструменти для прецизійного формоутворення деталей з високолегованих та жароміцних сталей є найбільш складними у виготовленні, економічно привабливими та критично важливими у сегменті інструментального виробництва. Виготовлення таких інструментів шляхом електрохімічного зарощування зерен алмазу металом на електропровідному корпусі відоме давно. Проте їх виготовлення за найкращими традиційними технологіями стикається із значними складнощами і потенціал таких алмазних виробів реалізується лише на 15—20 %.

Мета. Удосконалення виробництва високоточного абразивного інструменту для обробки високолегованих та жароміцних сталей на сучасних оброблювальних центрах з числовим програмним керуванням.

Матеріали й методи. Електрохімічне осадження покриттів проводили за оригінальною методикою. Мікроструктуру одержаних покриттів вивчали за допомогою скануючої електронної мікроскопії та рентгенівської дифрактометрії. Міцність утримання алмазних зерен у зв'язці вимірювали на розробленому пристрої.

Результати. Запропоновано технологію виготовлення високоточних одношарових шліфувальних інструментів шляхом електрохімічного осадження металу. Показано, що між сталевим корпусом та шаром металу, що утримує алмазні зерна, створюється тонкий шар електропровідного полімеру з високою адгезією як до корпусу, так і до металу. Це зебезпечує міцне утримання абразивних зерен та високий ступінь рівномірності їх розміщення, що наразі є недосяжним для традиційних технологій, а також посилює стійкість гострих кромок профілю як найбільш вразливих ділянок інструменту.

Висновки. Вперше створено та апробовано новий клас високоточного профільного інструменту, який дає можливість імпортозаміщення на машинобудівних підприємствах України, а також виходу на зовнішні ринки.

Ключові слова: прецизійні алмазно-абразивні інструменти, шліфування, електрохімічне осадження металу.