UDC 621.922.025 **doi: 10.20998/2078-7405.2026.104.05**

IMPROVING THE EFFICIENCY OF USING DIAMOND GRINDING WHEELS ON THE ORGANIC BINDER BY CALCULATING THE RATIONAL STRUCTURE AND INTRODUCTION OF ULTRADISPERSED DIAMOND

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Received: 29 March 2026 / Revised: 15 April 2026 / Accepted: 26 April 2026 / Published: 15 May 2026

Abstract. *The article presents one of the options for developing scientifically based recommendations for choosing a rational combination of the strength of the binder, the size of the diamond grain, the concentration of diamond grains with the physical and mechanical properties of different types of binders in the manufacture of diamond grinding wheels. The conducted studies have shown the feasibility of using detonation nanodiamond powders as a modifier of the polymer binder. The introduction of nanopowder into the polymer leads to an increase in microhardness by 23%, and the recommended mass fraction of nanodiamond should be about 1% of the weight of the binder. It is possible to use such polymer compositions in the diamond layer of standard grades, which theoretically will increase their hardness due to constant thermal conductivity.*

Keywords: *diamond grinding wheels; organic binder; nanodiamond.*

1. Problem statement

At present the process of manufacturing of diamond wheels on the organic binder is characterized by high labor intensiveness and low productivity, high consumption of expensive diamond grains and, as a consequence, the high cost of the process of further exploitation of diamond wheels. It is necessary to increase the reliability and quality in the manufacture of diamond-abrasive tools, which is indispensable to its effective use in production. Manufacturing of diamond-abrasive tools is based on the establishment of physical laws and technological patterns of grinding process, as well as a comprehensive understanding of the diamond layer destruction process. Up to now there are no scientifically grounded recommendations for choosing the rational combination of the binder strength, grain grade, concentration with the physical-mechanical properties of different types of binders. Available recommendations for the use of diamond wheels on various bonds are general in nature. Therefore, nonrational choice of component properties causes damage to diamond grains during sintering and excessive wear of the wheel in the operational phase of diamond tools [1, 2].

2. Analysis of recent research and publications

Analysis of recent research and publications showed that the problem of increase of diamond grinding efficiency is still relevant and modern methods of mathematical modeling can bring significant results. The studies of wear of diamond grinding wheels showed that more than half of diamonds loss occurs due to falling out grains from the binder. Therefore the study of the role of binders in the process of grinding is an important and necessary task. Despite the fact that the wear of binder depends on and is determined by the wear of abrasive grains, the binder has a very significant impact on the process of grinding the details. Optimal characteristic of the binder depends on many factors: chemical interaction of the binder with the metal to be processed, thermal effect of chip on the binder, etc. Problem of increase of binder efficiency is particularly relevant in view of the fact that in recent few years it is possible to improve significantly the available binders, despite the fact that they permit to use potential properties of abrasives by no more than 20% [3].

In international practice, simulation of technological processes has proved to be a great tool for the evaluation and optimization of cutting and grinding processes. Information about the interaction between the elements of the "tool – workpiece" system at grinding permits to choose selectively the process parameters in order to achieve the best quality of the workpiece, minimum cutting time or high economic indexes of grinding. Being based on an inclusive interaction between the system parameters, processing parameters and results of grinding, the simulation of grinding processes is widely used in theoretical and practical study of abrasive processes. [4]. Using modern software tools of computer modeling for grinding process it is possible to implement the numerous empirical experiments in virtual space and the search of the rational properties of the "binder – grain – workpiece" system as far back as the design phase of diamond-abrasive tools.

The aim of the study. The aim is to develop a methodology for determining the optimal combination of strength properties of the elements of the grinding wheel, which will ensure the integrity of diamond grains in the manufacture and operation of the diamond grinding wheel on an organic binder.

Basic research results. During the study the original techniques for calculating the optimal properties of diamond grinding wheel for processing of different groups of materials (superhard materials, hard metals, ceramics, and so on) have been developed.

In particular, the method of three-dimensional dynamic simulation of the deflected mode of diamond grinding area has been developed. For the first time the software package LS-DYNA has been applied in regard to grinding process, that allowed to follow step by step the dynamic change of equivalent stresses, temperature, strain and so on of the system «binder – grain – material-to-be-processed» [5].

The algorithm for grinding process simulation and the creation of three-dimensional model can be represented as a sequence: the creation of three-dimensional geometry of the object of research, the creation of the finite element mesh of the object components, parameterization of the mesh, parameter assignment of the material behavior patterns, determining the properties of the contact interaction, assignment of the loads on the components of the system, analysis of the results.

A wide range of materials behavior is realized in LS-DYNA. To implement the grinding process simulation a few models that correspond to the plastic or elastic behavior of the material was used. For simulation of organic binder the solid body model (initial mechanical properties of the material: elastic modulus *E*, shear modulus *G*, Poisson's ratio μ, mass density of material ρ) was used. Metal-catalyst in the diamond grain, metal coating and workpiece were described by the model of plastic material behavior, which implements the basic Hooke's law up to the conditions of von Mises plasticity, ie the fourth criterion of strength. Series of computational experiments allows to obtain the dependence of limit equivalent stress in the system on the compound alloy content in the grain, its brand or the concentration of grains in the diamond-bearing layer (Figure 1., Figure .2)

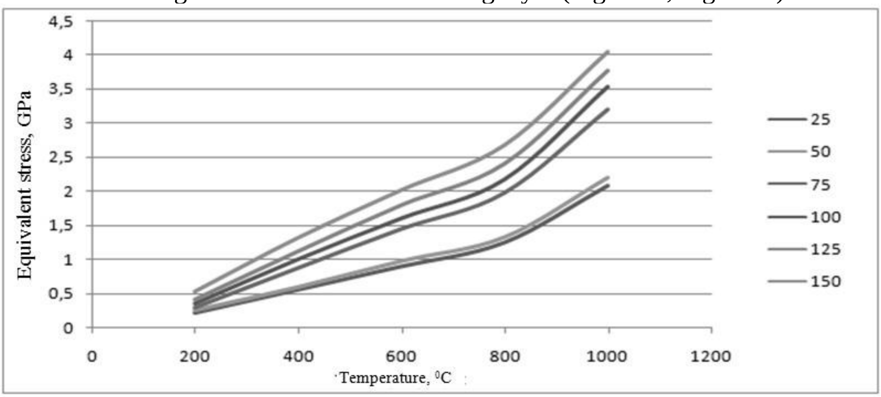

Fig. 1 – Dynamics of change of stress in the system «diamond – binder» in granularity of grains 63/50 on the temperature in the grinding area.

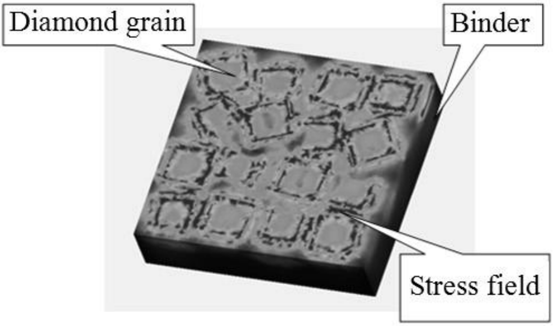

Fig. 2 – Distribution of stresses in the system «binder – grain – metal phase» with grain concentration of 150%.

In the operating phase of diamond grinding wheel of various grit sizes, concentration and grain drade, the modification of the standard nickel coating of synthetic diamond using ultradispersed diamond is proposed. In addition, ultradispersed diamond was also added to the resinbinder during sintering, which allowed to improve the adhesion between diamonds and organic binder of the wheel. Recently information about the possibility of further improvement of the properties of metal, in particular nickel coatings is available. This can be achieved owing to addition agents and obtaining new composite coatings that compare favorably with pure nickel coatings because of their physical and mechanical properties [6]. Special attention should be paid to the chemical reduction of nickel coatings with the inclusion of nano (ultradispersed) diamonds. Such composite coatings significantly improve the characteristics of conventional nickel coatings: increase strength, improve wear resistance, increase microhardness, anti-adhesion and anti-friction properties, reduce friction coefficient, increase the load carrying capacity, thermal stability, etc.

To get in practice the composite coatings based on chemically deposited nickel and nanodiamonds, the previously known technique to obtain nickel-plated synthetic diamonds has been modified. The technique includes the following stages (Figure 3):

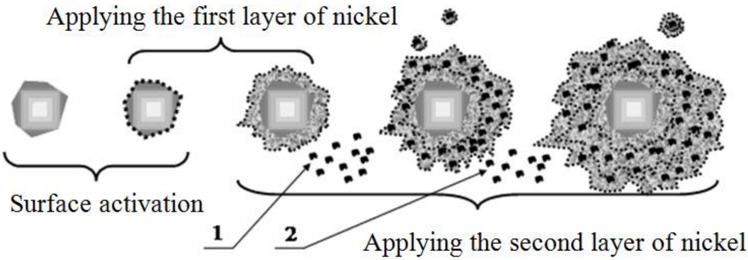

Fig. 3 – The sequence of chemical deposition of nickel coating with inclusions of nanodiamonds (1 – adding nanodiamond suspension during deposition of the second layer of nickel, 2 – adding nanodiamond suspension during deposition of subsequent layers of nickel).

Carried out tests of the resultant coatings have confirmed the theoretical backgrounds and composite coating with the addition ultradispersed diamond allowed to increase the performance of the diamond wheel by 27% compared with the wheel, which uses conventional nickel.

3. Modification of the polymer bond by the introduction of a detonation nanodiamond.

The bond, along with the grade, grain and concentration of the diamond grains, is the most important characteristic of the diamond grinding wheel. The quality of the bond determines the utilization rate of the potential of the diamond, the scope of application and performance of the diamond tool, productivity, economic efficiency and quality of grinding. More than 55% of the total range of produced binders is occupied by bonds on an organic binder, which is explained by the ease of manufacture and low cost of such diamond tools. At the same time, the problem of excessive wear of the organic (polymer) diamondiferous layer remains relevant. The standard modifier of the mechanical and chemical properties of the bond is the filler, the percentage of which varies along with the concentration of diamond grains. The properties of the filler may not be affected by thermal conductivity, hardness, coefficient of friction or ductility of the bond. For example, dispersed graphite, the content of which in the B2-01 bond is contained in the amount of 0.8% of the volume of the diamondiferous layer and significantly increases its antifriction properties. However, the most effective means of increasing diamond retention is the introduction of components that chemically interact with diamond into the bind. In this case, the strength of diamond retention depends on the adhesion activity of the bond components to the diamond surface and increases with increasing adhesion work. Given the linear dependence of the amount of filler and diamonds in the diamondiferous layer, there is a need to search for new modifying components that will allow changing the mechanical properties of the bond with a constant ratio of filler and diamond grains [11].

Studies conducted by foreign and domestic scientists have shown that one of the applications of ultrafine diamond is its use as a polymer modifier. Filling the aromatic polyamide phenylon C-2 with nanodiamonds makes it possible to increase the abrasive wear resistance of samples by 3.5 times, increase the modulus of elasticity by 104.5 MPa, and the compression yield strength by 6.5 MPa (Table 5.1) [99,107].

Detonation nanodiamond can be successfully used as an additive to such polymers as fluoroelastomers, polysilicones, isoprene rubbers (Table 5.1). When creating a composition from such polymers and nanodiamonds, the elastic modulus of the nanodiamond composite can be increased by 10 times, and the tensile strength is increased by 1.3 to 11 times [99].

Table 5.1 – Strength characteristics of phenyl and phenyl-based nanocomposites.

Polymer Grade	Modulus of Elasticity (MPa)	Tensile Strength (MPa)
Fluoroelastomer *Nanodiamond Composite*	8.5 92	15.7 173
Polysilicon *Nanodiamond Composite*	19 53	52 154
Isoprene rubber *Nanodiamond Composite*	7.7 12.3	20.5 28.2

As you know, the binding element of bakelite bonds is a polymer - phenolic binder SFP-012A. The binder is a mixture of pillow-case phenol-formaldehyde oligomer SF-012 with a curing agent - hexamethylenetetramine. Taking into account the positive effect of nanodiamond on the mechanical properties of polymers, it is suggested that the addition of nanodiamond can change the physical and mechanical properties of standard polymer bond grades, increasing their hardness, modulus of elasticity, and at the same time reduce the temperature in the microcutting zone due to changes in the frictional properties of the diamondiferous layer [3].

To confirm the hypothesis, samples of the diamondiferous layer were jointly created, in which a modifying component in the form of a nanodiamond was introduced. To avoid nanodiamond agglomeration and uniform distribution of nanopowder particles in the polymer binder SFP-012A, pulverbakelite was mixed with an aqueous suspension of nanodiamond and evenly dispersed in the resulting emulsion. Next, the emulsion was completely dried with subsequent mixing using ultrasonic vibrations. The resulting composite was further sintered using the standard technology for manufacturing diamond wheels on a polymer bond.

The effect of the presence of nanodiamond particles on the hardness of bakelite was studied on two types of samples. The first is a B2-01 bundle based on the binder SFP-012A and the content of urotropin (hexamethylenetetramine) is equal to 6% by weight, the second is a similar composition of the polymer SFP-012A, filler and 6% wt. GMTA with the addition of 0.5%, 1% and 2% wt. nanodiamond. The composition of two types was made by sintering rings with a size of 125x3x3 mm (Fig. 5.5).

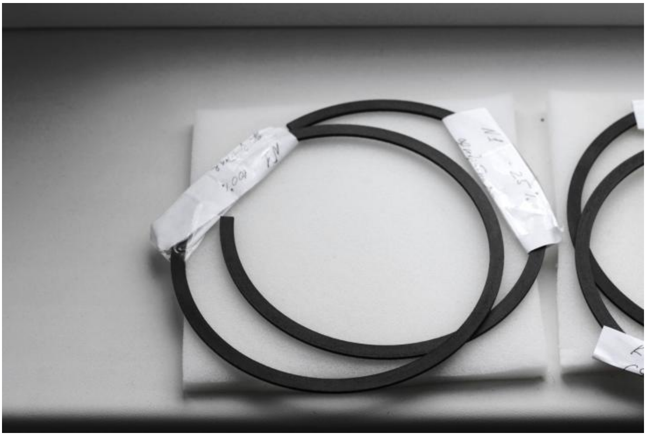

Figure 5.5 – Prototypes of a polymer diamondiferous layer with a size of 125x3x3 mm.

Hardness measurement on the PMT-3 device at a load of P = 50 g with a diamond pyramid with an angle at the apex of 136° showed that the introduction of nanodiamond particles into the polymer binder leads to an increase in the Vickers microhardness by 16 to 23%. Thus, the hardness of the bond sample without the presence of nanodiamond was 78 HV. When ultrafine diamond with a mass fraction of 0.5% was introduced into the composite, the hardness of the composition increased by 16% and amounted to 91 HV. The largest increase in hardness was observed on a sample with a 1% nanodiamond content (96 HV). With a nanodiamond content of 1.5% by weight. the hardness was 93 HV.

Thus, the studies carried out have shown the expediency of using detonation nanodiamond powders as a modifier of a polymer binder. The introduction of nanopowder into the polymer composition leads to an increase in microhardness by 23%, and the recommended mass fraction of nanodiamond should be about 1% of the bond weight. It is possible to use such polymer compositions in the diamondiferous layer of standard grades, which will theoretically increase their hardness with constant thermal conductivity.

4. Conclusions and prospects for development.

1. The physical nature of the synthetic diamond destruction, where the decisive factor is the temperature at the microcutting area is established. It is need to control this factor, along with force.

2. It is established that metal phase material and its percentage of the volume of the diamond influences significantly on the diamond grains efficiency. For example, the replacement of compound alloy with prevailing Mn content by the compound alloy with Ni reduces the probability of failure under conditions of force and thermal load by 27%.

3. From the calculations one can see that the concentration of diamond grains in diamond-bearing layer of the wheels can be significantly reduced compared to conventional values used in serial production.

4. As a result of the investigations it is determined that in contrast to the conventional thickness of the metal coating on the diamond surface within 56 – 100%% wt., the thickness of the coating should be recommended specifically for each graininess. For example, 50/40 – 80/63 from 175 to 200%, 100/80 – 160/125 from 150 to 175%, 200/160 – 400/315 125% wt.

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ПІДВИЩЕННЯ ЕФЕКТИВНОСТІ ВИКОРИСТАННЯ АЛМАЗНИХ ШЛІФУВАЛЬНИХ КРУГІВ НА ОРГАНІЧНОМУ ЗВ'ЯЗУЮЧОМУ МАТЕРІАЛІ ШЛЯХОМ РОЗРАХУНКУ РАЦІОНАЛЬНОЇ СТРУКТУРИ ТА ВИКОРИСТАННЯ УЛЬТРАДИСПЕРСНОГО АЛМАЗУ

Анотація. *У статті представлено один із варіантів розробки науково обґрунтованих рекомендацій щодо вибору раціонального поєднання міцності зв'язуючої речовини, розміру алмазного зерна, концентрації алмазних зерен із фізичними та механічними властивостями різних типів зв'язуючих матеріалів у виробництві алмазних шліфувальних кругів. Проведені дослідження показали доцільність використання детонаторних наноалмазних порошків як модифікатора полімерної зв'язуючої речовини. Щоб уникнути агломерації наноалмазів і рівномірного розподілу нанопорошкових частинок у полімерній зв'язуючій речовині SFP-012A, пульвербакеліт змішували з водною суспензією наноалмазу та рівномірно дисперсували в отриманій емульсії. Далі емульсія повністю висушувалася з подальшим змішуванням за допомогою ультразвукових вібрацій. Отриманий композит додатково спікався за стандартною технологією виготовлення алмазних кругів на полімерному пов'язку. Вплив наявності частинок наноалмазу на твердість бакеліту вивчався на двох типах зразків. Перший — це зразок B2-01, заснований на зв'язуючій речовині SFP-012A, вміст уротропіну (гексаметиленететраміну) становить 6% за вагою, другий — схожий склад полімеру SFP-012A, наповнювача і 6% ваги GMTA з додаванням 0,5%, 1% і 2% ваги наноалмаза. Композиція з двох типів здійснювалася шляхом спікання кілець розміром 125x3x3 мм. Додавання наноалмазу у полімерний зв'язувач призводить до збільшення мікротвердості по Вікерсу на 16–23%. Таким чином, твердість зразка пов'язку без наявності нанодіаманта становила 78 HV. Коли в композит додавали ультрадрібний алмаз з масовою часткою 0,5%, твердість складу збільшувалася на 16% і становила 91 HV. Найбільше зростання твердості було зафіксовано на зразку з вмістом наноалмазу 1% (96 HV). Вміст нанодіаманту становить 1,5% за вагою, твердість становила 93 HV. Введення нанопорошку в полімер призводить до збільшення мікротвердості на 23%, а рекомендована масова частка наноалмазу має становити близько 1% від ваги зв'язуючої речовини. Можливо використовувати такі полімерні композиції в алмазному шарі стандартних сортів, що теоретично підвищує їхню твердість через більш високу та постійну теплопровідність.*

Ключові слова: *алмазні шліфувальні круги; органічний зв'язуючий матеріал; нанодіамант.*