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SPECIFICITY OF USING DIAMOND MICROPOWDERS IN WHEELS ON METALLIC BONDS

Abstract. *Some issues related to the possibility of increasing the efficiency of shaping blade tools from polycrystalline superhard materials by diamond grinding are considered. It has been established that one of the ways to increase the efficiency of using diamond micropowder grains in circles is to apply thick metal coatings on them. The use of embossed metal coatings on diamond grains can significantly extend their cutting resource. This is explained on the one hand by a stronger adhesion of the coating material to the diamond surface compared to the components of the binder, and on the other hand, a significant increase in the contact surface of the coated grain with the binder of the circle. It was established that the strength of metal and ceramic ligaments should be consistent with the strength of diamond grains sintered with it, and the concentration and graininess of the latter have a significant impact on the integrity of the grains in the sintered layer.*

Keywords: *superhard materials; grinding; coating; modeling; cutting area; thermal stresses; bond stiffness; diamond consumption of a circle.*

1. Problem statement. According to many researchers [1], [2], [3], at present one of the most promising methods of manufacturing edge cutting tools and other products out of polycrystalline extra hard materials (PEHM) is still grinding with wheels on diamond grinding micropowder base. Its efficiency remains essential even by rough grinding, since the process productivity and wearing of wheels have satisfactory values. However, this technology is, certainly, not economically sound, taking into account the costs of PEHM.

2. Analysis of the latest research and publications. The latest research on this subject shows, that the increase in the efficiency of generating edge tools out of PEHM owes to the field of using the wheels on the diamond micropowder base [4], [5], [6]. In this case, however, the well-known contradiction between the grain size and their stability in the wheel bond becomes stronger. First of all, it considerably affects the value of the specific charge of diamonds. It has been confirmed that one of ways to increase the efficiency of diamond micropowder grains in wheels is to coat them with thick metallic layers.

3. The objective of the research. The objective of the paper is to define certain peculiarities of using diamond micropowders with thick relief metallic coatings in wheels on strong metallic bonds.

4. Basic research materials. With regard to the conditions of processing PEHM by current-carrying wheels on the diamond micropowder base, the coatings with the thickness of half the size of the coated grain are of special interest. The theoretical base of obtaining such coatings has already been developed, and the coating technology itself is well practiced [7], [8]. The most widely used coating at present contains 56 % of nickel, however the percentage of metal content can be changed on customer's demand. The above mentioned technology allows us to obtain relief coatings. At the same time, there occurs the possibility to adjust the degree of the surface relief of grains down to nanostructural level (coatings with relief, velvet and smooth surfaces).

The model of a diamond grain with a coating of sufficient accuracy degree can be presented, for example, in the form of a sphere with harmonic surface (fig. 1), the equation of which in spherical coordinates will be like this:

$$\rho(\varphi, \theta) = \frac{Z_{init.a.g.}}{2} \cdot (1 + k_t) \cdot [1 + k_A \cdot \sin(n\varphi) \cdot \cos(n\theta)],$$

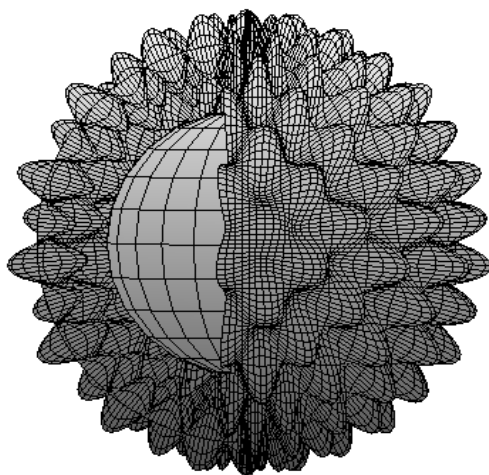


Figure 1 – A diamond grain model with metallic relief thick coating

ρ - radius-vector length, φ and θ - zenith and azimuthal angles accordingly;

k_t - relative factor of average coating thickness (the ratio of average coating thickness to the average size of the initial diamond grain $Z_{init.a.g.}$ (Fig. 2);

k_A - relative amplitude factor of coating thickness variation;

n - quantity of surface peaks in axial section.

Using relief thick metallic coatings on diamond grains allows to considerably extend the cutting life of the tool. The reason for this improvement is, on the one hand, the stronger adhesion of the material to the diamond surface, in comparison with the bond components, and on the other

hand, the considerable extension of the surface contact area of the coated grain with the wheel bond. As it has already been stated, this fact is particularly important for fine-grained wheels, as the increase in the specific charge of diamond wheels affects the reduction of the grain size.

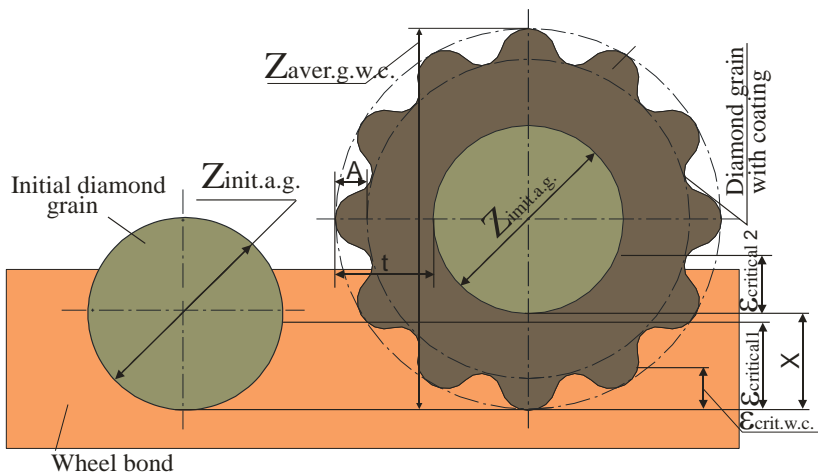


Figure 2 – The role of diamond grains coatings ($Z_{init.a.g.}$ -initial average grain; $Z_{aver.g.w.c.}$ -average grain with coating; $\epsilon_{crit.w.c.}$ -critical with coating)

In Figure 2, at the expense of using the coating on a diamond grain the increase in the depth of grain sealing in the bond by the value X which numerically equals the coating thickness, can be achieved.

Thus, when using the relief thick coatings, a part of the coated grain, sealed in the bond, can reach significant value, if $Z_{coat.} \approx 2 \cdot Z_{init.}$ it can equal $X \approx Z_{init.} / 2$, i.e. it can play an independent role in holding the grain in the bond. We can suggest with confidence that even in case of destruction, the grain will be held by its metallic coating, and will continue on performing useful work on metallic transition of PEHM for some time. It should positively affect the operating ratio of diamond grains, which is essential for micropowder diamond grains.

If thick coating has relief, it will lead to even greater extension of the surface area of the grain in general, and in particular, extension of the sealed

area in the bond. Additionally, in comparison with coatings with smooth surface of the same size, the conditions of mechanical fastening of the grain essentially improve. They allow to evenly distribute the load, acting on the grain by cutting, thereby essentially decreasing the value of the critical sealing in the bond ($\varepsilon_{critical1} < \varepsilon_{critical2}$, $\varepsilon_{aver.} < \varepsilon_{critical1}$, $\varepsilon_{critical2} \rightarrow \min$, Fig. 2).

With the coated grain being bigger than the initial one ($Z_{coat.} = Z_{init.} + 2 \cdot t$, where t – is the coating thickness), the initial mass of grains (before applying the coating) must be reduced appropriately, even taking into account the ability to allocate the coated grains in the diamond-carrying layer.

Provided that the size of the coated grain should equal approximately the closest standard size ($Z_{coat.} \approx Z_{stand.}$), the first approximation may show that their quantity in the volume unit of the diamond-carrying layer of the wheel should also be the same, i.e. $n_{coat.} \approx n_{stand.}$. This may lead to the reduction of the initial micropowder mass, which means the decrease in real diamond grains concentration in the wheel. The table below shows a model correlation between the standard granularity and granularity of diamond micropowder grains with thick coating (for the case $t \approx Z_{init.} / 2$).

Table – Model correlation between the standard granularity and granularity of diamond micropowder grains with thick coating*

Initial grains	$Z_{init.}$	60/40	40/28	28/20	20/14	14/10
Coated grains	$Z_{coat.} \approx Z_{stand.}$	100/80	80/63	50/40	40/28	28/20

With the grain in the form of ellipsoid of revolution, the initial mass of grains $M_{stand.}$ with the granularity $Z_{init.}$ can be calculated by the formula:

$$M_{init.} = M_{stand.} \cdot \frac{Z_{init.max} \cdot Z_{init.min}^2}{Z_{stand.max} \cdot Z_{stand.min}^2} = M_{stand.} \cdot \frac{Z_{init.max}}{Z_{stand.max}} \cdot \left[\frac{Z_{init.min}}{Z_{stand.min}} \right]^2 \quad (1)$$

Similarly the concentration of the coated grains in the wheel can be designated as $C_{aver.}$, and the initial grains without any coating can be

designated as C_{init} . In this case, given that $Z_{coat.} = Z_{init.} + 2 \cdot t$ an equation can result on the basis of (1). The equation allows to define the necessary concentration of the coated grains in the wheel and to calculate the values of concentration of grains in the wheels depending on the coating thickness and the granularity of diamond micropowders. This equation is given by:

$$C_{coat.} = C_{init.} \cdot \frac{Z_{init.max}}{Z_{init.max} + 2 \cdot t} \cdot \left[\frac{Z_{init.min}}{Z_{init.min} + 2 \cdot t} \right]^2 \quad (2)$$

At the same time the marginal initial diamond grains concentration in the diamond-carrying layer of the wheel was considered to be the concentration value of 200% (when diamond takes 1/2 of the volume of the working layer) on the basis of empirically determined value of maximum volume filling by diamond grains, which does not exceed $\pi / \sqrt{40} \approx 0.5$ by V.N. Bakul and his colleagues [9]. Graphic interpretation of the dependence (2) is presented in Figure 3.

The role of diamond wheel characteristics (concentration, granularity and bond material) by processing PEHM is significant, when there is practically no embedding of diamond grains into the work material.

The fact is particularly true for the situation, when the influence of factors has complex character. Therefore, for example, increasing the quantity of grains up to a certain level in contact with PEHM, as a rule, improves the quality of cutting edges. Then, however, (owing to durability increase in the processing zone) it can lead to intensification of chipping process.

From the technological point of view there should be an optimum combination of parameters of the diamond-carrying layer characteristics in the wheel, which provides the required quality of cutting edges of the tool. Considering the complexity of the phenomena, occurring in the grinding zone, the most optimal characteristic of the wheel with the coated grains can be defined empirically, taking into account technical restriction (2), considering the possibility of allocating coated grains in the diamond-carrying layer.

The coating thickness is a very important parameter, the size of which affects all stages of diamond wheel life cycle. At its preproduction phase, the mix material affects the ability to allocate the coated grains in it, at the sintering stage of the diamond-carrying layer its size determines grain integrity, and at the grinding stage it determines its cutting durability in many respects.

Another important aspect of coating diamond micropowder grains, is creating a diamond-carrying layer of the wheel, is the ability to avoid such a

negative phenomenon as comminution of grains with forming large conglomerates, which may negatively affect the quality of the processed surface.

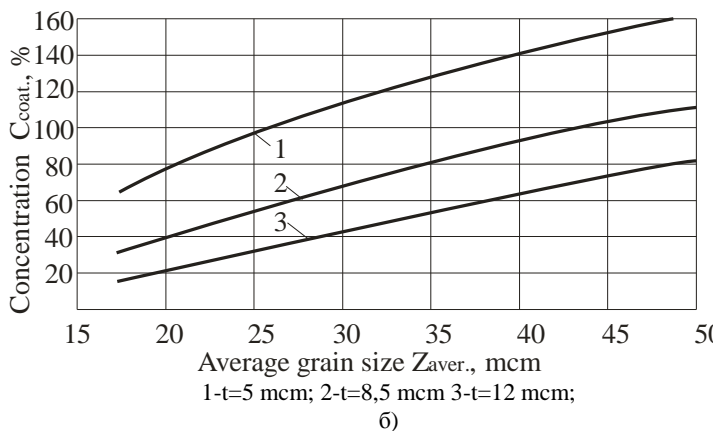
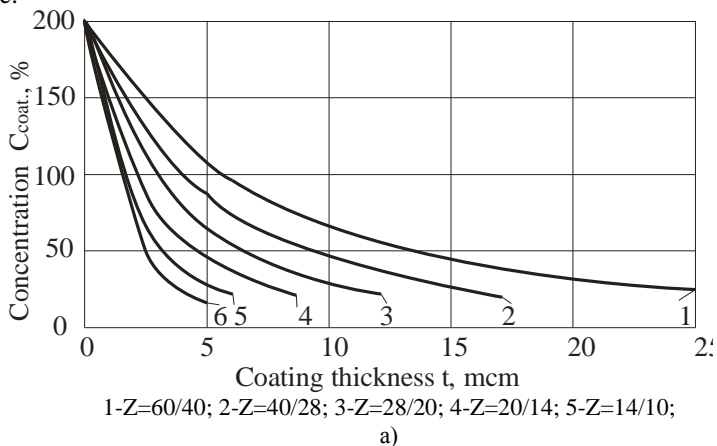


Figure 3 – Dependences $C = f(t, Z_{aver.})$ for coated grains

Using 3D modeling of the diamond-carrying layer deflected mode of the wheel by sintering allowed to establish the fact that the durability of metallic and ceramic bonds should be coordinated with the durability of sintered grains in the bond. The concentration and granularity of the sintered grains considerably affects the integrity of grains in the sintered layer. For example,

using diamond wheels with the concentration of diamonds more than 40 % essentially complicates the process of receiving the diamond-carrying layer, the characteristics of which would correspond the estimated one [10]. Such wheels do not improve the realization of conditions of technological stability.

It is known [11], [12], [13] that concerning the grinding efficiency of PEHM, particularly on the diamond base, the optimum concentration of grains in the wheel should be less than 100 % (when diamond takes 1/4 of the volume of the working layer), and can be defined by the experiment-calculated method.

It is known that the higher the durability of the grain is (depending on its mark), the greater their concentration in the diamond-carrying layer of the wheel can be (taking into account the preservation of the initial characteristic of the wheel) [14], [15]. As opposed to the grinding grains of the wheels on diamond base, when using diamond micropowders does not enable to choose the mark of the grain, since out of two existing marks only one is recommended for diamond processing – ACH (micropowder with high abrasive ability). However, one of the advantages of using micropowders is a much smaller quantity of metal inclusions in their structure in comparison with grinding grains, for example those of AC6 mark. This advantage predetermines lower internal tension in them at high-temperature sintering of the diamond-carrying layer. It is possible to assume that micropowder grain durability can be altered by choosing the coating thickness. It will enable to increase the diamond concentration value in the diamond-carrying layer of the wheel, when it is not technologically limited (2).

It is well known that at processing hard-to-cut materials it is often required that the value of diamond grains concentration in the wheel should be less than 100 %. By manufacturing glass products, for example, it is stipulated by the necessity to allocate the material dispersion products in the intergranular space; when generating products out of PEHM, the restriction is power tension of the grinding process. There factors can be considered advantageous concerning using grinding wheels with the coated grains. The fact particularly concerns diamond micropowders, taking into account the quantity of grains in one carat [16], and, therefore, in the diamond-carrying layer of the wheel and per unit of its functional surface. According to our data [17], the number of grains per unit area of the working surface of the wheel can be calculated using the formula:

$$n = \frac{3 \cdot C}{200 \cdot \pi \cdot a^{3/2} \cdot (0,96 \cdot \bar{x}_M)^2} \quad (3)$$

With n being the number of grains piece/mm²; C – grains concentration in the wheel, %; $a = 0,6-0,8$ – the grain form factor; \bar{x}_M – the average size of grain, mm.

The calculations under the dependence (3) show (Fig. 4) that the forced decrease in concentration of grains on diamond micropowder base with coatings taking into account the restriction (2) is compensated by the increase in the number of grains in comparison with wheels on grinding micropowder base.

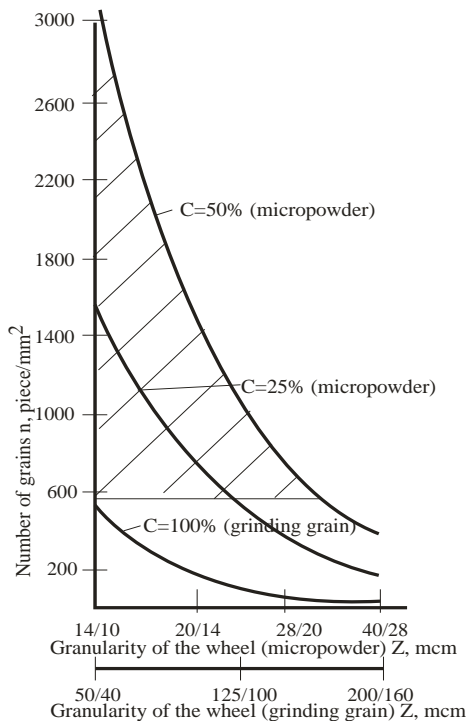


Figure 4 – Diagram of the dependence $n = f(Z)$

Hereby, for example, with the concentration of coated grains being $Z_{coat.} = 25\%$ their number per unit area of the working surface of the wheel with the granularity of $Z = 20/14$ will be considerably higher, than that of the wheel on the non-coated grinding micropowder base, with the wheel having the finest granularity (50/40), and the concentration of 100 %.

In order to define physical characteristics of the contact areas of the coated grain with the bond and the processing PEHM and to reveal the potential reserves of the grinding process the theoretical and experimental research of the deflected mode of the system “wheel bond - diamond grain - relief thick coating - processing material” has been conducted, taking into consideration the existence of the metal phase in the grain. The calculations have shown that the presence of the metallic coating on the diamond grain considerably amends the deflected mode of the system.

Particularly, it has been defined that the relief thick coating on the diamond grain essentially decreases the tension rate at the border “grain – bond” under the same conditions of thermal and power loading of the system (Fig. 5); the fact can be explained by the substantial contact surface extend of the coated grain with the wheel bond. This confirms the fact that the grains can be better held in the bond, and, therefore, their cutting resource increases.

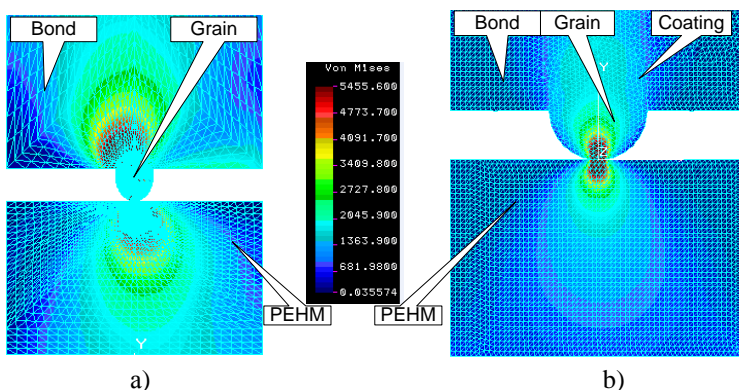


Figure 5 – Visualization of surface impact on 3D deflected mode in the system:
a) – without coating; b) – with the Ni based coating (Z=20/14)

At the same time the obtained data allow to define another essential fact: the relief thick coatings contribute to the increased tension in the processing material. The fact can also be explained by the increase in the contact surface of the coated grain with the wheel bond, therefore the rigidity of system “bond - grain - processing material” increases.

This deduction is of utmost importance, taking into account the fact that the removal of allowance occurs at the expense of fragile microdestruction of PEHM considering the lack of embedding of the diamond grain into the processing extra hard material. In order to achieve this, two major conditions

must be fulfilled: on the one hand, the presence of sharp micro and sub-micro edges on the grain, and on the other hand, the force of certain value.

As our research shows [13], such factor as wheel bond rigidity increases the pressure in the contact area of diamond grain with PEHM. Under the given conditions the role of the bond is even more evident. Such factors as thickness and durability of the coating, contribute to restraining the process of diamond grain macrodestruction, as they increase the effect of its 'compression'. The latter fact successfully affects the intensification of the removal of the allowance with processing PEHM.

The experimental research confirms the fact of essential decrease in the specific charge of diamond micropowder grains with thick relief metallic coatings, the value of which approximates that of the wheels on diamond micropowder base.

5. Conclusions and development prospects. Thus, on the basis of the foregoing theoretical analysis, we can state the fact that it is not only possible but also reasonable to use relief thick metallic coatings on diamond micropowder grains. Using relief thick metallic coatings allows to technically resolve the stated-above conflict between the necessity to decrease the grain size and the durability of holding them in the wheel bond.

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ОСОБЛИВОСТІ ВИКОРИСТАННЯ МІКРОПОРОШКІВ АЛМАЗУ В КРУГАХ НА МЕТАЛЕВІЙ ЗВ'ЯЗЦІ

Анотація. Розглянуті деякі питання, пов'язані з можливістю підвищення ефективності процесу формування лезових інструментів з полікристалічних надтвердих матеріалів алмазним шліфуванням. Дослідження останніх років показали, що резерв підвищення ефективності формування лезових інструментів з полікристалічних надтвердих матеріалів (ПНТМ) лежить в області використання кругів на основі мікропорошків алмазу. Встановлено, що одним із шляхів підвищення ефективності використання зерен мікропорошків алмазу в кругах є нанесення на них товстошарових металевих покриттів. Стосовно до умов обробки ПНТМ струмопровідними кругами на основі мікропорошків алмазу особливий інтерес представляють покриття, товщина яких може досягати половини розміру зерна. Використання на алмазних зернах рельєфних товстошарових металевих покриттів дозволяє істотно підвищити їх ріжучий ресурс. Це пояснюється з одного боку більш міцним зчепленням матеріалу покриття з поверхнею алмазу в порівнянні з компонентами зв'язки, а з іншого істотним збільшенням поверхні контакту покритого зерна зі зв'язкою круга. Використання методології 3D моделювання напружено-деформованого стану алмазозносного шару круга при спіканні дозволило встановити, що міцність металевої і керамічної зв'язок повинні узгоджуватися з міцністю алмазних зерен, що з нею спікаються а концентрація і зернистість останніх істотно впливають на цілісність зерен в шарі, що спікається. Використання, наприклад, алмазних кругів з концентрацією алмазів понад 40% істотно ускладнює отримання алмазозносного шару, характеристика якого відповідала б розрахунковій. Встановлено, що наявність на алмазному зерні рельєфного товстошарового покриття при тих же умовах термостійкого навантаження системи істотно зменшує величину напружень на кордоні «зерно-зв'язка», що можна пояснити значним збільшенням поверхні контакту покритого зерна зі зв'язкою круга. Експериментальні дослідження підтвердили факт істотного зниження питомої витрати зерен мікропорошків алмазу з товстошаровими рельєфними металевими покриттями, значення якого наближається до рівня кругів на основі шліфпорошків алмазу.

Ключові слова: надтверді матеріали; шліфування; нанесення покриттів; моделювання; зона різання; термічні напруження; жорсткість зв'язки; питомі витрати алмазів круга.