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THEORETICAL REASONING FOR EFFICIENT USE OF MICRO POWDERS IN DIAMOND WHEELS ON METALLIC BONDS

Abstract. *The article presents theoretical researches of improving the manufacturing process and the subsequent using of grinding wheels from diamond micro powders of diamond on current-carrying bonds, which allow to reduce the specific consumption of synthetic diamonds in the finishing operations of processing polycrystalline superhard materials It is proposed to use diamond grains with a metal coating in an abrasive tool. 3D analysis of the stress-strain state "diamond grain-coating-bond" system showed ways to reduce the probability of destruction of diamond grains during sintering of the diamond-carrying layer by changing the thickness of the coating, the elastic modulus of its material and other parameters. The calculated low values of the concentration of coated diamond grains provide a significant reduction in their specific consumption in the processing of polycrystalline superhard materials.*

Keywords: *diamond grinding, polycrystalline superhard materials, grinding wheel, stress-strain, specific consumption, metal coating, diamond grain concentration*

The last few years of processing polycrystalline superhard materials (PSM), proved the combined processes of grinding (sharpening), developed at NTU «KhPI» [1], to be highly efficient. This tendency can be confirmed by the fact that at the beginning of this century a well-known Swiss company «AGATHON Ltd.» produced a special machine «Agathon 350 Combi EcoDress», which implements the new technology of sharpening, applied to processing of multifaceted non-regrinding PSM plates on the base of boron nitrides [2].

Our research shows [3, 4] that by fine finishing of PSM tools it is possible to successfully use fine-grained (on diamond micro powders base) wheels on metallic bonds. It allows us to essentially raise the efficiency of this process concerning the processing productivity as well as its stability, which is favorably reflected in the quality of working elements of edge tools, made of super hard materials [5, 6]. However, the operating ratio of grains on diamond micro powders base is not high enough, which is confirmed by the high value of the specific consumption. This requires conducting further research, aimed at the perfection of the manufacturing process of grinding wheels with diamond micro powders and fine finishing of SPM.

The objective of the present work is to research the ways of increasing the efficiency of fine finishing of PSM by current-carrying wheels on the diamond micro powder base by improving the process of their manufacture.

In order to achieve the objective the theoretic and experimental research [7] of manufacturing the diamond layer of the wheels and grinding using the finite element method [8, 9] have been carried out.

In our opinion the principal causes for the increased consumption of fine-grained wheels is on the one hand the small closing depth of the bond, and on the other hand – the lack of recommendations to defining the optimum value of the wheel characteristic [10].

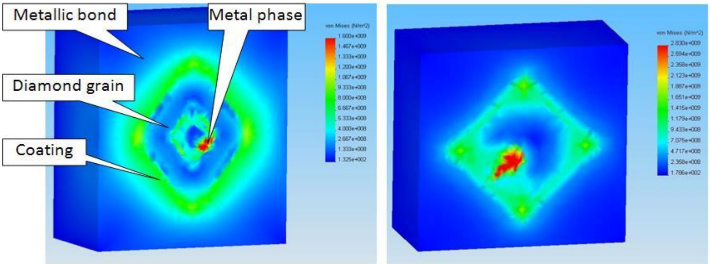
It is known [11, 12] that the effective way to improve operational properties of diamonds, to decrease their specific consumption, and to increase their processing productivity is diamond metallization. In some cases it leads to increasing the productivity and decreasing the specific consumption of diamonds to half as much again [13]. Plastic metallic coatings are the most practically feasible coatings (for example, on the *Ni* base), which are used for tools on organic bonds. Meanwhile, it is known that bad disclosure of cutting diamond faces interferes with successful usage of such coatings for the tool on metallic bond, which leads to loss of working capacity of the tool due to blunting [11]. However, it has been established that this downside has no significant effect on combined grinding processes, and there is no need to use grains with more expensive and complex coatings, made of transitive metal carbides.

Finite-element 3D analysis of the stress-strain state of the system "diamond grain–coating–bond" has shown, that at the stage of producing wheels (sintering of the diamond-carrying layer) the coating preserves the integrity of diamond grains (which can destruction at high temperatures and pressure [14]). At the stage of grinding it will contribute to its stability.

There is an assumption that with the increase in coating thickness (with a stronger carcass around the grain) the probability of preserving the integrity of the grain will increase at high temperature and pressure in the sintering zone of the diamond-carrying layer of the wheel. This fact has been confirmed by the calculations, the results of which are shown in figure 1.

It has been proved that the combination of the coating material and the bond material has the essential influence on the stress-strain state of the system "grain–coating–bond". A stronger bond should promote greater ability of the grain to counteract the breaking force.

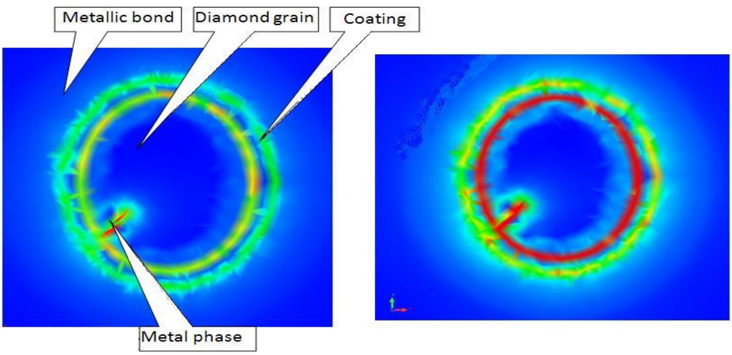
At high temperatures of diamond-carrying layer sintering of the wheel the metal phase material as well as its percentage has essential influence on grain destruction. The factor of thermal expansion of the metal phase is considerably higher, than that of a diamond, which can lead to occurrence of limiting pressure, striving to break it.



a) b)

Figure 1 – Influence of coating thickness on the stress-strain state of diamond wheel
a – coating thickness – 8 μm; b – coating thickness – 4 μm

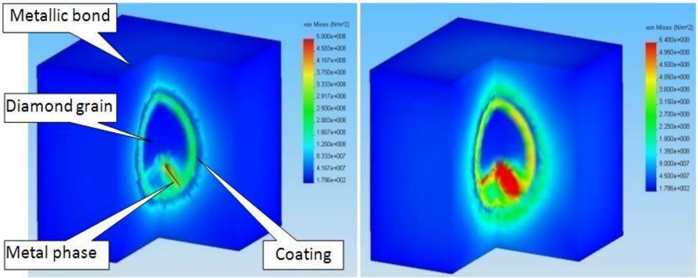
The increase in the elasticity module of the coating material also should promote increase in counteraction to the forces, striving to break the grain. The fact is illustrated in the results of our calculations in figure 2.



a) b)

Figure 2 – Influence of the coating material on the stress-strain state of the diamond wheel:
a – coating material – chrome; b – coating material – nickel

Thus, the higher the factor of thermal expansion of metal phase is, the stronger is the pressure in the diamond grain and the higher is the probability of its destruction by diamond wheel sintering (fig. 3).



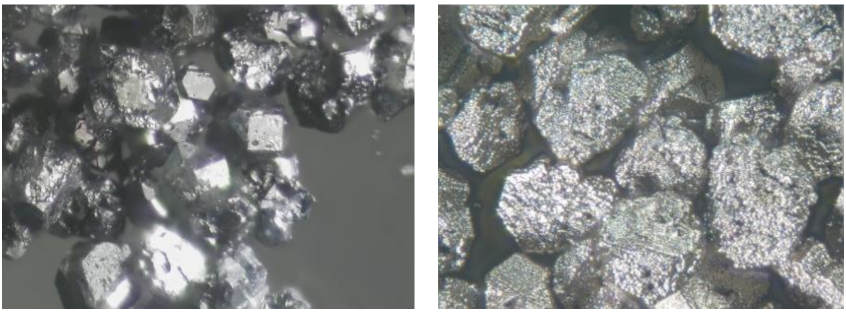
a) b)

Figure 3 – Influence of metal phase mark on 3D deflected mode in the coated diamond grain: a – *Cr*-based metal phase; b – *Fe*-based metal phase

At present at National Technical University «KhPI» the new perspective chemical technology of layering metallic (for example, nickel etc.) coatings on abrasive materials is being developed [15]. It is based on nickel sedimentation from acetic solutions. One of the types of the technology can be based on using nickel salts received during sewage treatment of diamond manufacture in the technology of chemical nickel plating of synthetic diamonds.

The most widespread coating is the coating with 56 % nickel content, however on demand of the customer, the coatings both with higher and with lower metal content can be layered.

Thus the technology of receiving a coating with a relief surface has been developed (fig. 4) with the ability to regulate the degree of its relief down to nanostructural level (a coating with so-called relief, velvet and smooth surfaces).



a) b)

Figure 4 – Diamond micro powders: a – without a coating; b – with a relief coating

Coatings of all kinds do not differ in their chemical composition and contain not less than 98 % of nickel. The phosphorus content of all kinds of coatings does not exceed 1 %.

It has been established, that the relief coating allows to essentially lower the relative critical depth of the grain sealing. The reason for this improvement is, on the one hand, the stronger adhesion of the material to the diamond surface, in comparison with the components of bond, (the diamond surface relief has less effect on the dependence of the coating adhesion strength with the diamond surface, which extends technological characteristics of coatings) 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 reduction of the grain size affects on increase the specific consumption of diamond wheels.

The scheme simulating the operating ratio of the diamond grain (fig. 5) shows that this can be achieved by increasing the grain sealing in the bond by a value of:

$$X = \frac{Z' - Z}{2}. \quad (1)$$

Wherein part of the coating *X*, sealed up in the bond can reach significant value ≈ *Z'/4* ≈ *Z/2* and play an independent role in the process of sealing the grain in the bond. Even in case of destruction, the grain will be kept by the coating and continue to perform useful work on removing an allowance off PSM. As a result, the operating ratio of diamond grains increases.

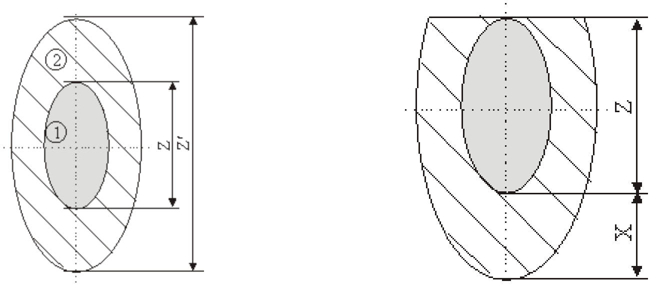


Figure 5 – Influence of the coating on size of grain sealing in the bond:
1 – diamond grain; 2 – coating

In perspective the issue of covering grains with multilayered coatings is of a certain scientific and practical interest.

Practicing combined processing of PSM with diamond wheels on grinding powders shows that in order to reduce the specific consumption of diamonds, it is essential to reduce their concentration down to 25 % [1]. This fact particularly concerns wheels on diamond micro powder base as the granularity (Z) reduction causes a rapid increase in the quantity of grains (n) on the working surface. As the coated grains increase in size (up to twice) it is natural therefore (taking into account their allocation on the wheel working surface) that their quantity ($n_{coat.}$) should be less than that of initial grains ($n_{init.}$). Considering the dependence $Z_{coat.} \approx Z_{stand.}$ (tabl. 1) the first approximation shows that their number should be equal, that is $n_{coat.} \approx n_{stand.}$.

Table 1 – Approximation between the standard granularity ($Z_{stand.}$) and the granularity of diamond micropowder grains with thick coatings ($Z_{coat.}$)

Initial	Z_{init}	60/40	40/28	28/20	20/14	14/10
Standard	$Z_{coat} \approx Z_{stand}$	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:

$$M_{imit.} = M_{stand.} \cdot \frac{Z_{init.\max} \cdot Z^2_{init.\min}}{Z_{stand.\max} \cdot Z^2_{stand.\min}} = M_{stand.} \cdot \frac{Z_{init.\max}}{Z_{stand.\max}} \cdot \left[\frac{Z_{init.\min}}{Z_{stand.\min}} \right]^2 \qquad (2)$$

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:

$$Z_{coat.} = Z_{init.} + 2t, \qquad (3)$$

where t – is the coating thickness an equation can result on the basis of (2). 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 micro powders. This equation is given by:

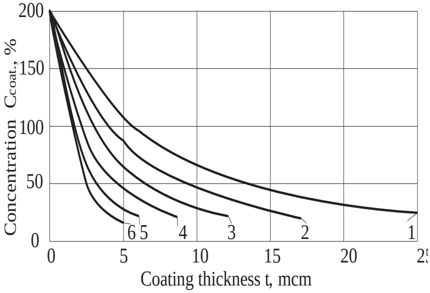
$$C_{aver.} = C_{init.} \cdot \frac{Z_{init.\max}}{Z_{init.\max} + 2t} \cdot \left[\frac{Z_{init.\min}}{Z_{init.\min} + 2t} \right]^2 \qquad (4)$$

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 % 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. Graphic interpretation of the dependence (4) is presented in figure 6, calculation results for are given on table 2.

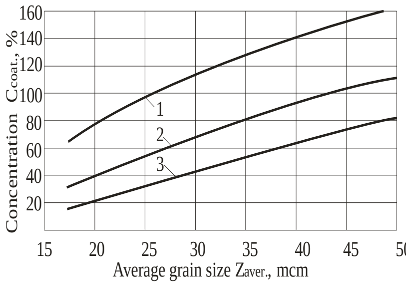
Table 2 – The concentration of grains of diamond micro powders with a coating for $n_{coat.} \approx n_{stand.}$ and $Z_{coat.} \approx Z_{stand.}$

Granularity $Z_{init.}$, μm	60/40	40/28	28/20	20/14	14/10
Concentration $C_{aver.}$, %	15,0	9,9	14,0	12,5	12,5

It is essential to note that the increase in grain size due to coating can be construed as a benefit considering manufacturing of wheels, as it promotes their smoother spreading on the working surface (i.e. it promotes the elimination of excessive grain aggregation in separate places of the diamond-carrying layer of the wheel).



1 – Z= 60/40; 2 – Z= 40/28;
3 – Z= 28/20; 4 – Z= 20/14;
5 – Z= 14/10



1 – t=5 μm; 2 – t=8,5 μm; 3 – t=12 μm

Figure 6 – Dependences $C = f\,(t, Z_{aver})$ for coated grains

It is reasonable to assume that wheels with such concentration will contribute to the stability of the grinding process due to essential increase in number of grains (allocated on the working surface), participating in cutting (with their simultaneous reduction of the working height), and therefore, to provide considerable decrease of the specific consumption.

Thus, the results of the conducted research allow us to draw the following conclusions:

1. The process of using diamond wheels can be considerably improved by using coated diamond micro powder grains.

2. In order to preserve the integrity of diamond grains by sintering diamond wheels it is reasonable to use the coatings with high elasticity module and low factor of thermal expansion. The best effect thereby can be achieved by using diamond grains with metal phase with low factor of thermal expansion.

3. The use of multilayered thick relief coatings is considered effective in terms of reducing the specific consumption of diamond grains.

4. Diamond wheels on diamond micro powder base with coating are supposed to have the concentration of 10–15 % and 20–30 % by processing PSM on diamond base and boron nitride base accordingly, which should allow us to essentially decrease the number of grains, which drop out of the bond and have not exhausted their cutting resource.

In perspective, carrying out theoretical and experimental research of coated grains interworking with the processing of polycrystalline superhard materials, and also the research of technical and economic parameters of wheels on diamond micro powder base with coating in real grinding process is of major scientific and practical interest.

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ТЕОРЕТИЧНЕ ОБГРУНТУВАННЯ ЕФЕКТИВНОГО ЗАСТОСУВАННЯ МІКРОПОРОШКІВ В АЛМАЗНИХ КРУГАХ НА МЕТАЛЕВИХ ЗВ'ЯЗКАХ

Анотація. *Сучасні методи обробки полікристалічних надтвердих матеріалів (ПНТМ) дозволяють застосовувати на чистових операціях обробки інструментів алмазні кола на основі дрібнозернистих мікропорошків алмаза на металевих зв'язках. При цьому коефіцієнт використання зерен мікропорошків алмазу недостатньо великий. Стаття представляє теоретичні дослідження, спрямовані на вдосконалення процесу виготовлення шліфувальних кругів з мікропорошків алмаза на струмопровідних зв'язках, що дозволяють знизити питомі витрати синтетичного алмазу на чистових операціях обробки таким інструментом ПНТМ. В якості ефективного способу поліпшення експлуатаційних властивостей дрібнозернистих алмазів, зниження їх питомої витрати в абразивному інструменті і підвищення продуктивності подальшої обробки цим інструментом пропонується застосування зерен з металевим покриттям. При цьому добре розкриття різальних кромок металізованих зерен алмазу забезпечують комбіновані процеси шліфування, що застовуються в практиці обробки ПНТМ.3D аналз напружено-деформованого стану системи "алмазне зерно–покриття–зв'язка" на етапі спікання алмазоносного шару кругів показав шляхи зниження ймовірності руйнування алмазних зерен за рахунок зміни товщини покриття, модуля пружності його матеріалу й інших параметрів. Отримані розрахунковим шляхом значення концентрації алмазних зерен з покриттям, в рази менші тих, що традиційно використовуються, забезпечують істотне збільшення відсотка зерен, які знаходяться на робочій поверхні круга і беруть участь в різанні, а, отже,і значне зниження величини їх питомої витрати.Подальший науковий інтерес становляють дослідження взаємдії алмазних зерен, що мають покриття, у тому числі і багатошарові,з оброблювальними ПНТМ і техніко-економічних показників реальних процесів шліфування алмазними кругами на їх основі*

Ключові слова: *алмазне шліфування; полікристалічні надтверді матеріали; шліфувальний круг; напружно-деформований стан; питома витрата; металеве покриття; концентрація алмазних зерен.*