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SPECIFIC ENERGY CAPACITY OF PROCESSING AND ENERGY EFFICIENCY FOR PROCESS OF GRINDING WITH WHEELS FROM SUPERHARD MATERIALS

Valerii **Lavrinenko**[1][0000-0003-2098-7992], Volodymyr **Solod**[2][0000-0002-7516-9535], Predrag **Dašić**[3][0000-0002-9242-274X],Yevgeniy **Ostroverkh**[4][0000-0002-8926-1324]

[1]V. Bakul Institute for Superhard Materials NAS Ukraine, Kyiv, Ukraine
[2]Dniprovsk State Technical University, Kamianske, Ukraine
[3]Engineering Academy of Serbia (IAS), Belgrade, Serbia
[4]National Technical University «Kharkiv Polytechnic Institute», Kharkiv, Ukraine
lavrinenko@ism.kiev.ua

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Abstract. *The analysis of modern research shows that when evaluating the specific energy intensity of the abrasive processing process, one should pay attention not only to the indicators of grinding power and material removal rate, but also to the indicator of the wear of the abrasive tool, which we will show below for the grinding tool made of superhard materials. It is shown that the traditional method of estimating the specific energy capacity based on the ratio of the grinding power to the processing productivity does not provide an adequate solution, since with it the specific heat capacity of processing exceeds the specific heat capacity of melting of the processing material by almost an order of magnitude. Therefore, it is the application of a new approach to the assessment of the specific energy intensity of diamond grinding, taking into account the wear of the working layer of the diamond wheel, and makes it possible to estimate the indicators of the specific energy intensity of grinding and the energy efficiency coefficient. It has been proven that when estimating the specific energy capacity of grinding metal-ceramic composite materials consisting of a low-melting and refractory component, the latent heat capacity of melting of the low-melting component should be taken as the basis. It is shown that the plastic mode of grinding occurs precisely when the specific energy capacity of grinding, taking into account the wear of the wheel, becomes close to the specific heat capacity of melting of a brittle material.*

Keywords: *specific energy capacity of grinding; energy efficiency coefficient; grinding;abrasive tool; wheel of the superhard materials; wear, friction.*

1. INTRODUCTION

Relevant studies have shown that the energy consumed by the processing industry makes up to 37% of the total global energy consumption and produces up to 21% of greenhouse gas emissions worldwide [1]. At the same time, 20% of energy is used to overcome friction, and 14% of energy loss is caused by wear and tear, including energy to manufacture new parts and idle equipment. In addition, taking into account the cost of maintenance work due to wear, the total cost of costs due to wear is 35% of the cost of overcoming friction [1]. That is, the field of industrial production requires more energy consumption due to the need to overcome friction and wear. In addition, researchers pay great attention to the issue of reducing the energy intensity of machining processes. This is due to the fact that, for example, in the manufacture of engineering products, the specific share of the cost of energy consumption only for processing is from 15 to 25% [2] and increases over time. Thus, the specific share of the energy component in the cost price of machine-building products used to not exceed 5–7%, and over the past decades it has increased to 18–25% [3] and has a tendency to further increase. And this tendency is largely connected with the fact that the achievement of the necessary accuracy of processing requires an increase in the specific energy of processing. Methods for modeling and optimization of parameters of the grinding process were used in works [4-5].

2. MODERN PUBLICATIONS ON ENERGY ISSUES DURING ABRASIVE PROCESSING

Examining the specific energy during material removal processes at the micro-scale offers a deeper comprehension of the energy transfer across various material removal regimes. Breaking down specific energy into sliding, plowing, and cutting components facilitates the examination of how grain properties, process parameters, and mechanical properties impact the energy transfer between different phases of material removal. An inclusive framework for specific energy consumption (SEC) in abrasive cut-off operations by integrating individual models of primary and secondary rubbing energies, specific plowing energy, and specific cutting energy was proposed [6]. The strong correlation observed between the formulated model and empirical data underscores the concept that specific energy consumption (SEC) exhibits asymptotic behavior relative to the material removal rate.

As it is presented in Fig. 1, with the increase in material removal rate, there is a corresponding decrease in specific energy consumption. Mirroring trends are observed in prior studies on grinding operations. The notion of ductility aids in comprehending the overall energy consumption of materials. In ductile materials, the malleability of the workpiece materials resulting from heat generation, along with their higher fracture toughness compared to brittle materials, escalates the machining challenge, consequently demanding higher specific energy during metal cutting[6]. Hence, the specific energy consumption of ductile materials such as OFC-C10100 and Al-1100 is higherin comparison to other materials operating at the same material removal rate. During the grinding process of hard and less ductile materials, the rate of crack propagation while cutting with abrasive grits increases, thereby decreasing the energy needed to deform the material. Therefore, hard and less ductile materials such as SS201 and Al 7075 require relatively lower specific energy consumption. Among the materials, Inconel-718 exhibits higher specific energy consumption, due to its elevated hardness, increased strength, and greater resistance to cutting[6].

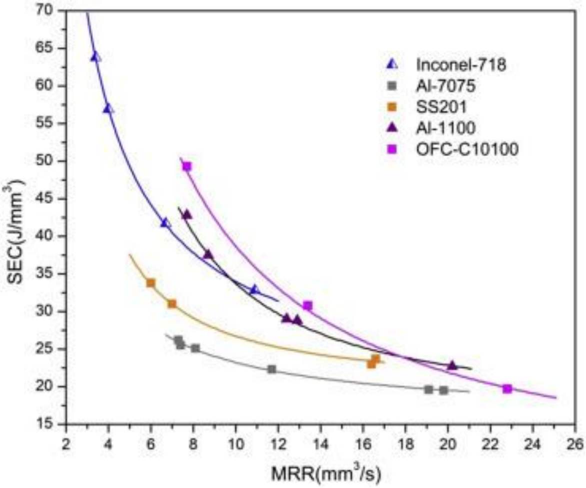


Fig.1. SEC relationship with material removal rate for materials [6].

The critical grinding depth of the ductile-brittle transition (DBT) is a crucial processing parameter that ensures machining of brittle materials in the ductile mode. However, predicting the critical grinding depth is challenging due to the multitude of grain interactions resulting from the random distribution of grains on the wheel. Innovative grinding force and energy model has been developed to anticipate the critical grinding depth, taking into account the random interactions among multiple grains [7]. In order to verify the model's accuracy, experimental validations have been performed on single crystal silicon. During this procedure, the interactions between the grains and the workpiece are examined through the actual heights of grain protrusions and the random distribution of grains. Addressing this deficiency, paper [7] introduces an analytical model for grinding force and energy to forecast the critical depth of ductile-brittle transition in the grinding of brittle materials (Fig. 2). The surface generation mechanisms during the ductile-brittle transition are thoroughly explored through the utilization of both numerical simulations and experimental techniques. The results indicate that plastic plowing and brittle fracture are the predominant modes of material removal during the grinding of brittle materials. Furthermore, the experimental validation results suggest that the proposed model is able to accurately predict the actual critical grinding depth, with an average deviation of less than 9.2%. At the end, utilizing the proposed model, a thorough investigation is conducted into the impact of grinding conditions on the critical grinding depth. The critical grinding depth rises with higher grinding speed, whereas it decreases with increasing feed speed. Thus, this study not only offers a novel approach for forecasting the critical grinding depth but also advances the comprehension of the ductile-brittle transition mechanism in the machining of brittle materials[7].

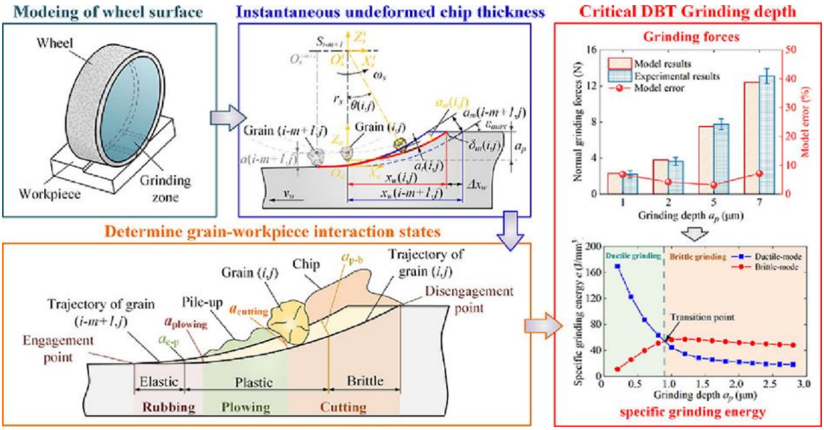
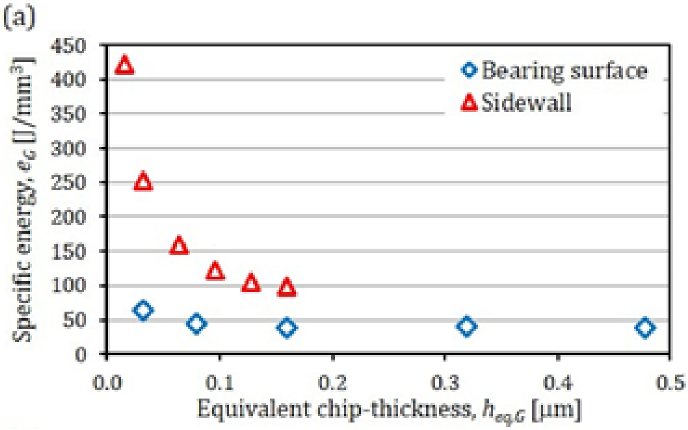


Fig. 2. An analytical grinding force and energy model for predicting the critical DBT depth in grinding of brittle material is proposed in paper [7].

Modeling and quantification of the abrasive processesis challenging task due to the stochastic nature of the abrasive-tool surface characteristics. On the other hand, their macroscopic geometry and motion patterns are typically clearly defined and easily regulated on machine tools. To address this apparent inconsistency, a new integrated modeling framework is established based on the concept of aggressiveness [8]. It encompasses the diverse geometry and motion patterns of a workpiece in motion, relative to an abrasive surface. The point-aggressiveness, as a dimensionless scalar quantity derived from the vector field of relative velocity and the vector field of abrasive-surface normals, represents the key parameter. This fundamental process parameter directly influences common process outcomes such as specific energy, abrasive-tool wear, and surface roughness. The theory of aggressiveness is experimentally confirmed through its application to various abrasive processes, including grinding, diamond truing, and dressing. In these applications, the aggressiveness number is correlated with the aforementioned measured process outputs. The major issue in grinding crankshafts is to avoid thermal damage caused by grinding, particularly on the sidewalls of the crankpin [8]. The higher temperatures that caused thermal damage primarily rely on the specific energy of grinding, calculated as the ratio of grinding power and material removal rate, $e_G = P_G/Q_G$. As it is presented in Fig. 3b, it is obvious that the aggressiveness number comprehensively captures the geometry and motion characteristics of the process, as indicated by the coefficient of determination close to 1. On the other hand, creating a plot of specific energy versus commonly used process parameters that do not fully consider geometry and motion characteristics, such as grinding equivalent chip-thickness $h_{eq,G}$ (Fig. 3a), might result in misinterpretation of observed variations in measured results.



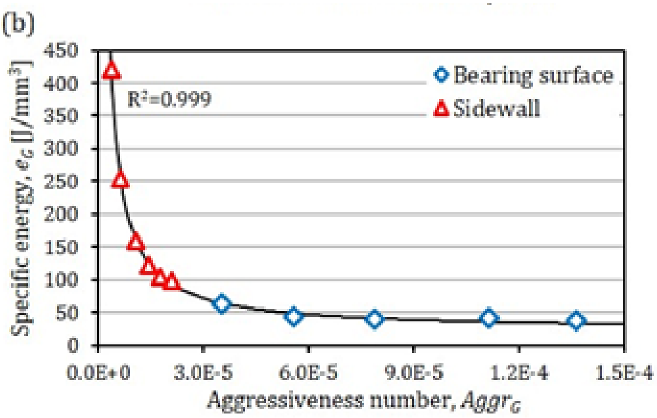


Fig. 3. Grinding specific-energy e_G (a) equivalent chip-thickness and (b) aggressiveness number [8].

3. FORMULATION OF THE PURPOSE OF THE RESEARCH

Summarizing the above short review, we pay attention to the following. The more plastic the processed material is, the greater is the specific energy of its grinding. The specific energy intensity of grinding is affected by the cutting conditions and the conditions for fixing the abrasive grains. With a small equivalent chip thickness and under the conditions of grinding the side surfaces, the specific grinding energy increases significantly due to the increase in the process of friction and wear of the wheel grains. And when grinding support surfaces, the thickness of the chips does not affect and the specific energy of grinding remains unchanged. As a result, it affects the depth of grinding of the ductile-brittle transition, which is an important processing parameter that guarantees the processing of brittle materials in the ductile regime. The above in the articles [1, 6–8] shows that when estimating the specific energy intensity of the abrasive processing process, in addition to the indicators of grinding power and material removal rate, attention should also be paid to the indicator of wear of the abrasive tool, which we will show below for the grinding tool from superhard materials (SHM), which was the purpose of this article.

4. PRESENTING MAIN MATERIAL

We will remind that the main direction of reducing energy costs for physical processes in the cutting zone is the optimization of processing modes according to criteria related to the level of specific energy consumption during cutting. These are [8–10]:

criterion of the minimum specific energy intensity of cutting

$$e = A_{ct}/V = N_{ef}/P_{ct} = N_{ef}/(v \cdot S \cdot t) \rightarrow min \qquad (1)$$

where A_{ct} – cutting work; V – is the volume of the cut material layer; N_{ef} – effective cutting power; P_{ct} – cutting performance; v – cutting speed; S – feed; t – cutting depth,

and the criterion of maximum energy efficiency (CEE) of the cutting process

$$K_e = \Delta w \cdot V/N_{ef} = \Delta w/e \rightarrow max \qquad (2)$$

where Δw is the specific energy density of the processed material.

In article [11], it was clarified that formula (2) includes the specific energy density of the processed material, which is interpreted as the specific heat of fusion, and the processes of blade processing are interpreted as plastic deformation, and the process of abrasive processing (grinding) – as a physical process of melting. That is, here we see a certain analogy of the specific energy capacity of abrasive processing, as the specific heat capacity of melting of the processed material.

Let's figure out what we know from the literature on abrasive processing processes from the point of view of the specific energy intensity of processing. For example, the authors [8–10] define the specific energy capacity as the ratio of the effective power of processing to its productivity, then $e=\Delta E=N/Q$ (dimension J/m^3). This is characteristic of both blade processing [9] and abrasive processing [8, 10]. As it was shown in the work [1], the calculations according to this formula and the data available in the literature for abrasive processing are included in the range of 20–200 kJ/cm^3. And actually we can see it from the data in Fig. 1 (ranges 20–65 J/mm^3 [4]), Fig. 2 (ranges 20–160 J/mm^3 [7]) and Fig. 3 (the range of 40–60 J/mm^3 for the support surface [8], we will consider the range for the side surface later). The author of the article [1] additionally applied his own data for calculations according to the above formula of the specific energy intensity of grinding (ΔE) of R6M5 steel. It is shown that when grinding R6M5 steel with productivity (Q) of 400 mm^3/min. the power indicator (N) was 0.4 kW, then ΔE = 60 kJ/cm^3, at Q = 1000 mm^3/min and N = 1.4 kW, ΔE = 84 kJ/cm^3, and at Q = 2000 mm^3/min and N = 2.0 kW, ΔE = 60 kJ/cm^3. That is, these data actually coincide with the range indicated above. However, the average specific energy intensity of steel grinding is about 60 kJ/cm^3, and the specific heat of fusion of steel is 0.64

kJ/cm^3. That is, there is a contradiction. At one time, attention was drawn to this in the work [1], where it was shown that the calculation of the specific energy intensity of grinding according to the traditional indicator in relation to the effective power of grinding to the productivity of processing does not completely correspond to reality, it is more energy-intensive than the process of diamond-abrasive processing and exceeds the heat capacity of melting of the processed material by 10 to 100 times. That is, the indicated contradiction is present, and it is especially relevant for the processes of grinding with SHM wheels, which are expensive and require an economically justified application, justified primarily by the reduction of energy costs during processing. In order to find ways to resolve the above-mentioned contradiction, in our opinion, it is more correct to estimate the specific energy consumption of diamond-abrasive processing with SHM wheels due to the additional consideration of the wear of the working layer of the wheel, as indicated in the article [8]. Let's pay attention to the significant increase in the specific grinding energy for processing the side surfaces with a grinding wheel, where the conditions for holding abrasive grains are worse and, as a result, the specific grinding energy increases sharply (see Fig. 3). The formula for determining the specific energy intensity of processing, for grinding processes with SHM wheels, taking into account the wear of the working layer of the SHM wheel, is substantiated in [1] and has the form:

$$e = E_{se} = 2{,}4 \cdot 10^7 \cdot N_{ef} \cdot q_p / (Q \cdot K \cdot \gamma_{shm}),\ kJ/kg, \tag{3}$$

where: N_{ef} – effective grinding power, *kW*; q_p – relative consumption of SHM grains in the wheel during grinding, *mg/g*; Q – grinding productivity, *mm^3/min*; K – is the relative concentration of SHM grains in the wheel, %; γ_{shm} – SHM grain density, *g/cm^3*.

Let's return to the energy efficiency indicated above. As we saw from the previous paragraph, for diamond-abrasive processing (grinding) processes, Δw from formula (2) can be interpreted as the specific heat capacity of melting of the processed material, as it occurs in a number of researchers. At the same time, some indicate that the specific energy capacity of the abrasive treatment process should be lower than the heat capacity of melting, others – what is higher, and those that correspond to it. Let's express it for equation (2) as follows: the energy efficiency for the first case must be $K_e > 1$, for the second – $K_e = 1$, and for the third case $K_e \geq 0.8$. That is, here we already get certain initial values of energy efficiency for abrasive processing, and as we can see, it should not be less than 0.8.

Since, as we have shown above, 100 times more heat is pumped into steel during grinding than is needed for its melting, the energy efficiency (CEE) according to formula (2) will be

$$K_e = \Delta w/\Delta E = 0{,}64/60 = 0.01067.$$

As we can see here, the energy efficiency CEE is significantly lower than even the expected minimum efficiency of 0.8 indicated above. That is, there is a contradiction both in the specific energy intensity of grinding and in terms of energy efficiency CEE. Now let's return to the energy efficiency indicated above according to formula (2). As we have seen from the above, for the processes of grinding wheels of superhard materials, Δw can be interpreted as the specific heat capacity of melting of the processed material. But the indicator – e, namely the specific energy intensity of processing, according to the proposed new approach, taking into account the wear of the working layer of the SHM wheel [1], has the form of formula (3) and then the energy efficiency CEE for grinding processes with SHM wheels will have the form:

$$K_e = \Delta w/e = \Delta w \cdot Q \cdot K \cdot \gamma_{shm}/(2{,}4 \cdot 10^7 \cdot N_{ef} \cdot q_p), \qquad (4)$$

where: $\Delta w$is the specific heat of melting of the processed material, *kJ/kg*; Q – grinding productivity, mm^3/min; K is the relative concentration of SHM grains in the wheel, %; γ_{shm} – SHM grain density, g/cm^3; N_{ef} – effective grinding power, *kW*; q_p – relative consumption of SHM grains in the wheel during grinding, *mg/g*.

In order to more clearly evaluate the above, let's try, as an example, to first evaluate the temperature level in the surface layer of high-speed cutting steel R6M5 during grinding with cubic boron nitride (cBN) wheels without cooling, when this level will be the highest. And in the future, compare these data with the specific energy capacity of grinding according to formula (3) and the values of energy efficiency according to formula (4) for the process of grinding R6M5 steel with cBN wheels on different connections. Samples of plates made of R6M5 steel measuring 5x30x60 *mm* were ground on a mod universal sharpening machine 3V642 wheels 12A2-45° 125x5x3x32 with different characteristics of their working layer. Grinding modes: wheel speed – 25 *m/s*, longitudinal feed – 2.4 *m/min*, transverse feed – 0.05 *mm/f*. The grinding productivity was 600 mm^3/min. It was found that the highest temperature level in the grinding zone (T_{gr}) is observed in wheels on the metal-polymer bond – V1-13, slightly lower in the ceramic bond K17, noticeably lower in the polymer bond V2-08, and the lowest in the polymer – ceramic connection – PK-03. For comparison, we found the temperature level on the direct surface of the plates when cutting thermocouples during the use of an abrasive wheel made of white electro corundum with the characteristics of an abrasive layer 25A25SM1K8. The temperature in the processing zone here was 750 °C. That is, all the above wheels from cBN are here with a grinding performance of 600 mm^3/min. Do not exceed the ignition temperature of high-speed steel R6M5

(620 °C), in contrast to a wheel made of electro corundum, where such ignition is observed on the treated surface of the steel. This is described in more detail in the article [11].

Now let's return to the issue of energy consumption of grinding and energy efficiency for the above conditions of grinding R6M5 steel with cBN wheels. The calculation of the specific energy capacity according to formulas (2) and (3) is given in the Table 1. Analysis of table data shows the following. The value of the specific energy capacity of grinding according to the traditional indicator, calculated according to the ratio (2), is from 21 to 30 *kJ/cm*^{3}, and the value of the specific heat capacity of melting of R6M5 steel is – 0.68 *kJ/cm*^{3}, that is, here too we see that as the specific heat of fusion of P6M5 steel is exceeded by at least 30 times during grinding. And in the case when we apply a new approach to the calculation of the value of the specific energy capacity according to formula (3), then here we already see more conscious values. For a wheel with a PK-03 connection, the specific energy capacity of grinding is 72.6% of the specific heat capacity of melting of R6M5 steel, for wheels with connections V2-08 and K17 it actually corresponds to it, and for a wheel with a connection V1-13 already the specific energy capacity of grinding exceeds the specific heat capacity of melting of R6M5 steel by 14.3%. That is, it is the new approach to calculating the specific energy intensity of grinding wheels with SHM that allows it to be adequately evaluated.

Table 1 – Calculation of the specific energy capacity and energy efficiency for the process of grinding R6M5 steel without cooling with different wheels from cBN (source data from work [11]) with productivity Q=600 *mm*^{3}*/min*. (T_{gr} is the temperature value in the grinding zone).

Characteristics of the working layer of the wheel	Effective grinding power, *kW*	T_{gr}, °C	Relative consumption of CBN in the wheel during grinding, *mg/g*	Specific energy capacity of grinding		K_e
				according to relation (2), *kJ/cm*^{3}	according to formula (3), *kJ/kg*	
KP 100/80 PK-03 100	0,29	510	1,84	29	61	1,377
KP 80/63 V2-08 100	0,21	525	3,48	21	83	1,012
KP 100/80 K17 100	0,25	605	2,89	25	83	1,012
KP 80/63 V1-13 100	0,30	610	2,80	30	96	0,875

As evidenced by the analysis of the Table. 1 shows a certain correspondence between the temperature in the grinding zone and the indicators of specific energy capacity and energy efficiency. The higher the temperature in the grinding zone, the higher the specific energy capacity and the lower the energy efficiency. At the same time, as we drew attention to in the article [12], when the specific energy capacity of grinding becomes close to the specific heat capacity of melting of a brittle material, a plastic mode of processing occurs. The concept of plasticity, presented in the article [6], helps to understand the total energy costs for processing materials. It is shown that the specific energy consumption during the processing of plastic materials is higher in comparison with other materials at the same rate of material removal. When grinding hard and less plastic materials, the rate of crack growth when cutting with abrasive grains is higher, which reduces energy consumption for material deformation [6]. For this reason, hard and less plastic materials require less specific energy during processing. At the same time, the article [7] proposed an analytical model of grinding force and energy for predicting the critical depth of DBT when grinding brittle material.

Recall that the above referred to more or less homogeneous instrumental materials. And what if our composite tool material consists of components that are quite heterogeneous in terms of thermophysical characteristics, for example, metal-ceramic hard alloys, where there is a relatively low-melting component (cobalt or nickel as a binder) and a refractory component (tungsten or titanium carbides). Accordingly, such components differ significantly among themselves in terms of specific heat of fusion 263 *kJ/kg* (2.31 kJ/cm^3) for cobalt and 273 *kJ/kg* for nickel (2.43 kJ/cm^3) and for 1100 *kJ/kg* (4.62 J/cm^3) for TiC and WC. In order to find out how to estimate the specific energy intensity of grinding such composite materials, we analyzed the data for calculating such energy intensity for hard alloys VK8 and T15K6 (binder - cobalt), as well as tungsten-free hard alloy (TFHA) TN50 (binder - nickel) with the involvement of initial data from work [12] (Table 2).

Table 2 – Calculation of the specific energy capacity for the process of diamond grinding of various tool materials (source data from the work [10]) with a wheel AS6 100/80 V11-2 100 with productivity Q = 525 mm^3/min.

Instrumental material	Effective grinding power, *kW*	Relative consumption of diamond in the wheel during grinding, *mg/g*	Specific energy capacity of grinding	
			according to relation (2), kJ/cm^3	according to relation (2), kJ/cm^3
Hard allow – VK8	0,90	0,7	103	82

Hard allow – T15K6	0,70	0,8	80	73
TFHA – TN50	0,70	2,2	80	201

Analysis of data Table 2 shows the following. When calculating the specific energy intensity of grinding according to the ratio (2), the obtained data fall into the already known range of 20–200 kJ/cm^3. And this means that, for example, in all the given tool materials, the specific energy intensity of grinding exceeds the specific heat of fusion of even their refractory component by 17 to 22 times. But let's pay attention to the fact that VK6, T15K6 and TN50 hard alloys contain a more easily melting binder: VK6 and T15K6 have cobalt, and TN50 have nickel. They are usually the first to be exposed to heat. And this means that calculations of the specific energy intensity of grinding according to the ratio (2) exceed the specific heat of fusion for cobalt by 35–45 times, and for nickel by 33 times. That is, such calculations do not provide an adequate estimate of the specific energy intensity of grinding. Now consider the calculations according to formula (3). As we can see (see Table 2), here the specific energy intensity of grinding does not even reach the specific heat capacity of melting of the binding hard alloy. But on the most difficult-to-process tungsten-free hard alloy TN50, the specific energy capacity of grinding is already approaching the specific heat capacity of melting nickel. The above allowed us to make an assumption that when estimating the specific energy intensity of grinding metal-ceramic composite materials consisting of a low-melting and refractory component (hard alloys), the latent heat capacity of melting of the weakest link, namely the low-melting component, should be taken as a basis.

Now let's consider instrumental mineral ceramics. There are no data on the specific melting energy here either, but there are data on its components: for Al_2O_3 it is 1108 *kJ/kg* [12], and for TiC – 1094 *kJ/kg* [12], i.e., for ceramics it will be Σ 1100 *kJ/kg*. This gives us the opportunity to estimate the specific energy intensity when grinding oxide-carbide ceramics (Table 3). We would like to point out that the calculation of the specific energy intensity of grinding VOK60 ceramics according to the above traditional ratio (2) was 35–45 kJ/cm^3. That is, it corresponds to the above range. Something else is interesting here. As we have already indicated above, the real specific heat capacity of steel melting is actually 2 orders of magnitude lower than the specific energy capacity of grinding, calculated according to the above-mentioned traditional indicator ΔE. And what do we have for oxide-carbide ceramics. The specific heat capacity of its melting is ~1100 *kJ/kg*, i.e., if recalculated, then Σ4.62 kJ/cm^3. And this means that if the calculations are carried out according to the traditional indicator ΔE, then for ceramics, as well as for steel, this indicator again significantly exceeds the specific heat of fusion, except that here it is not by 2 orders of magnitude, but only by an order of magnitude. And what really? Let's evaluate this, again, with the involvement of data from work [12] when grinding VOK60 ceramics with different diamond wheels (Table 3). It can be seen that relative to the specific energy of ceramic melting, the specific energy of its diamond grinding according to formula (3) is almost an order of magnitude lower.

Table 3 – Calculation of the specific energy capacity according to formula (2) of the process of grinding VOK60 ceramics with diamond wheels

Characteristics of the working layer of the wheel	Q, mm^3/min	N_{ef}, kW	q_p, mg/g	E_{se}, kJ/kg
AS6 100/80 MO20-2 100	800	0,66	0,53	30,0
AS4 100/80MA V1-13 100	1050	0,65	1,30	55,2

In addition, let's pay attention to the influence of the speed of rotation of the wheel. Consider this when grinding $Si_3N_4+B_4C$ ceramics, which can be used in plates for processing with impact loads and ceramic balls, and is a rather difficult-to-process ceramic (Table 4). As can be seen from the data in the Table 4, reducing the cutting speed also from 30 to 15 *m/s* immediately transfers processing to the mode of increased specific energy capacity, which actually approaches the specific heat capacity of melting, that is, to the plastic mode of grinding.

Table 4 – Grinding indicators of $Si_3N_4+B_4C$ ceramic plates with a productivity of 1000 mm^3/min with diamond wheels 12A2-45° 150x10x3x32 AS4 160/125 V1-13 100

Speed of wheel rotation, m/s	q_p, mg/g	N_{ef}, kW	E_{se}, kJ/kg	R_a, μm
30	2,8	0,95	182	0,28
15	14	1,0	960	0,45

5. CONCLUSIONS

1. The analysis of modern research shows that when assessing the specific energy intensity of the abrasive processing process, attention should be paid not only to the indicators of grinding power and material removal rate, but also to the indicator of wear of the abrasive tool.

2. It is shown that the traditional method of estimating specific energy capacity based on the ratio of grinding power to processing productivity does not

provide an adequate solution, since with it the specific heat capacity of processing exceeds the specific heat capacity of melting of processed materials by almost an order of magnitude, and therefore, any diamond processing of ceramics must immediately fall into the plasticity mode, which is not really the case. Therefore, it is the application of a new approach to estimating the specific energy intensity of diamond grinding, taking into account the wear of the working layer of the diamond wheel, and makes it possible to assess the possibility of adequately evaluating the specific energy intensity of grinding and the energy efficiency coefficient.

3. When estimating the specific energy capacity of grinding metal-ceramic composite materials consisting of a low-melting and refractory component (hard alloys), the latent heat capacity of melting of the low-melting component should be taken as a basis.

4. It is shown that the plastic regime occurs precisely when the specific energy capacity of grinding, taking into account the wear of the wheel, becomes close to the specific heat capacity of melting of the processing material.

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Валерій Лавріненко, Київ, Україна, Володимир Солод, Кам'янське, Україна,
Предраг Дашич, Белград, Сербія, Євгеній Островерх, Харків, Україна

ПИТОМА ЕНЕРГОЄМНІСТЬ ОБРОБКИ ТА ЕНЕРГЕТИЧНИЙ КОЕФІЦІЄНТ КОРИСНОЇ ДІЇ СТОСОВНО ПРОЦЕСІВ ШЛІФУВАННЯ КРУГАМИ З НАДТВЕРДИХ МАТЕРІАЛІВ

Анотація. *Аналіз сучасних досліджень свідчить про те, що чим більш пластичним є оброблюваний матеріал, тим більшою є питома енергія його шліфування. На питому енергоємність шліфування також впливають умови різання і умови закріплення абразивних зерен. Сучасні дослідження свідчать і про те, що при оцінці питомої енергоємності процесу абразивної обробки кругами з надтвердих матеріалів слід звертати увагу крім показників ефективної потужності шліфування і швидкості зйому матеріалу, також і на показник зносу абразивного інструменту, що нами далі і буде показано для шліфувального інструменту з надтвердих матеріалів (алмазів та кубічного нітриду бору). Доведено, що традиційний метод оцінки питомої енергоємності за відношенням потужності шліфування до продуктивності обробки не дає адекватного рішення, оскільки при ньому питома теплоємність оброблення майже на порядок перевищує питому теплоємність плавлення обробного матеріалу. Тому, саме застосування нового підходу до оцінки питомої енергоємності алмазного шліфування з урахуванням зношування робочого шару алмазного кругу, і дає можливість оцінити показники питомої енергоємності шліфування та енергетичний коефіцієнт корисної дії. Доведено, що при оцінці питомої енергоємності шліфування мінерало- та металокерамічних композитних матеріалів (оксидно-карбідних керамік та твердих сплавів), що складаються з низькоплавкої та тугоплавкової складової, за основу потрібно приймати приховану теплоємність плавлення саме низькоплавкої складової. Показано, що пластичний режим шліфування виникає саме тоді, коли питома енергоємність шліфування з урахуванням зносу кругу стає близькою до питомої теплоємності плавлення низькоплавкої складової крихкого матеріалу.*

Ключові слова: *питома енергоємність шліфування; енергетичний коефіцієнт корисної дії; шліфування; абразивний інструмент; круги з надтвердих матеріалів; знос; тертя.*