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THE INFLUENCE OF DIFFERENT HARDNESS OF THE TOOL MATERIAL ON THE WEAR OF SHM GRINDING WHEELS AND THE SPECIFIC ENERGY INTENSITY OF GRINDING

Valerii **Lavrinenko**[1][0000-0003-2098-7992], Volodymyr **Solod**[2][0000-0002-7516-9535], Volodymyr **Tyshchenko** [2][0009-0001-6473-5909],Yevgeniy **Ostroverkh**[3][0000-0002-8926-1324]

[1]V. Bakul Institute for Superhard Materials NAS Ukraine, Kyiv, Ukraine
[2]Dniprovsk State Technical University, Kamianske, Ukraine
[4]National Technical University «Kharkiv Polytechnic Institute», Kharkiv, Ukraine
lavrinenko@ism.kiev.ua

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Abstract. *It was established that conditionally viscous-brittle tool materials (high-speed steels and hard alloys) behave in the same way with an increase in hardness: wheel wear and the specific energy consumption of their grinding decrease. As the hardness of brittle tool oxide-carbide ceramics increases, both wheel wear and the specific energy consumption of grinding, on the contrary, increase. That is, an increase in the hardness of viscous-brittle materials facilitates the separation of elementary chips, less energy is needed for this, and accordingly the wear of the wheel and the specific energy consumption of their grinding are reduced. On brittle ceramics, with increasing hardness, there is no change in chip removal, but harder sludge becomes more abrasive and, as a result, the wear of the wheel and the specific energy consumption of their grinding increase. The conclusion from the literature that hard and less plastic materials require relatively less specific energy for grinding is confirmed by us when comparing materials of approximately the same hardness - hard alloys and ceramics. In ceramics, the energy consumption of grinding is actually four times lower than that of hard alloys.*

Keywords: *hardness; high-speed steels; hard alloys; ceramics; wear of SHM grinding wheels; specific energy intensity of processing.*

1. Introduction

The hardness of materials is related to a complex of mechanical properties, such as elasticity, plasticity, strength and yield limits, as well as micro- and nanohardness with such thermodynamic characteristics of substances – the energy of the crystal lattice, the energy of breaking crystal bonds, surface energy, melting point [1]. The hardness indicator characterizes a state of stress close to non-equilibrium compression, and thus determines the resistance to contact stresses arising in the working part of the cutting tool [2]. Therefore, for a cutting tool, the hardness of the tool material has a determining role. At the same time, it affects their processability, although there are certain features noted in publications [2–4]. Thus, the hardness of ceramics based on silicon nitride and silicon carbide has a smaller effect on their machinability than their density [3], and in [4] it is indicated that when grinding hardened steels, the cutting force does not depend on their hardness. The hardness of heat-resistant tool steels is determined by the dispersion and amount of carbides released during tempering, and residual austenite as a soft component [2]. Up to the hardness index of tool steels of 65 HRC, with increasing hardness, their strength also increases. However, their high hardness corresponds to a sharp decrease in viscosity [2]. That is why studies of the influence of the hardness index on the machinability of the tool material, when the hardness changes on one material, may be of some interest.

2. Modern studies on the influence of hardness on the operational characteristics of the material

Let us point out that modern researchers pay due attention to the hardness indicator, even in areas related to abrasive processing. Let us point out that modern researchers pay due attention to the hardness indicator. A vivid example is the polygonization of a railway wheel, which is a type of uneven wear of the material that worsens the directional stability of trains. On the railway, wheels and rails of different hardness are used, respectively HW and HR. An important factor affecting wear is wheel-rail hardness matching (ie HW/HR hardness ratio), which can affect the formation of a polygonal wheel. The results show that when fitting a softer rail, the wheel is less likely to become polygonal as HW/HR increases. When paired with a stiffer rail, the wheel showed early polygon initiation. The highest HW/HR ratio of 1.263 represented the best anti-polygonal condition for the wheel material [5].

Attention was also paid to hardness in the study [6], where the mechanism of plasticity with a deformation gradient was applied to study the size effect in the behavior of single-crystal copper during scratching. It is shown that the scratch hardness, which takes into account both the size effect and the dependence on the crystallographic direction, is a suitable property of the material for the evaluation of wear. Laser exposure and the use of a diamond tool with a negative front angle are promising methods of processing hard and brittle materials.

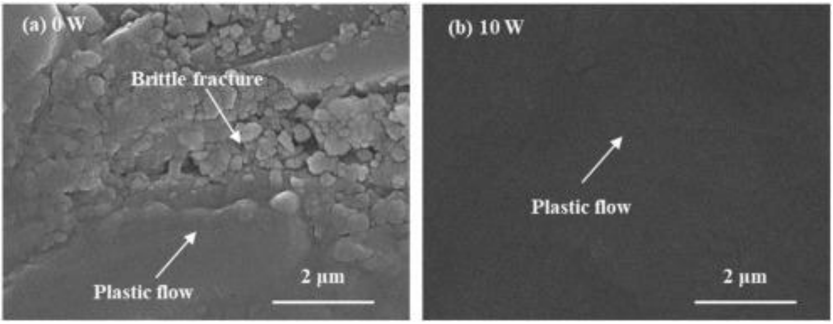

Fig.1. View of the surface, after processing with a diamond tool with grains with a front angle of −65° and without laser exposure (a) with exposure (b) with a power of 10 W [7].

In article [7], the mechanism of plastic removal of fused quartz is investigated. And here the effect on hardness is important. The results showed that ductile removal was improved with the laser due to hardness reduction and brittle fracture was reduced due to high hydrostatic compressive stress when using a diamond tool with negative rake grains (Fig. 1). Let's pay attention to the fact that we can observe this type of surface (see Fig. 1, a) under the conditions of diamond grinding of tool ceramics, when both plastic flow and brittle fracture zones are observed on the processed surface, which we described in more detail in the article [8].

In work [9], this was already considered for ultra-thin Ti-Al-Diamond wheels with variable abrasive sizes, concentration and shape, i.e. not due to a directed decrease in the hardness of the processed brittle material, but due to a change in the characteristics of the diamond layer of the wheel. Experimental results indicate that diamond abrasives significantly affect chip formation and material removal of SiC workpieces by changing the thickness of undeformed chips (Fig. 2). A theoretical analysis based on the classical brittle–plastic transition model shows that a hard but brittle SiC single crystal can be removed in the plastic regime using a relatively large abrasive size and low concentration in the work layer as long as the undeformed chip thickness is sufficiently smaller than the calculated critical cutting depth [9].

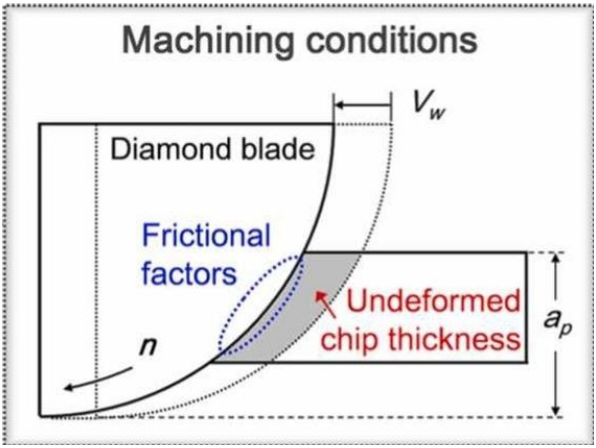

Fig. 2. Machining conditions: diamond blade – frictional factors – undeformed chip thickness

It was confirmed [10] that the specific energy during material removal has an asymptotic behavior with the speed of material removal, and as this speed increases, the specific energy consumption decreases. It is shown that in plastic materials, the viscosity of the material due to the release of heat and a higher fracture toughness compared to brittle materials increase the complexity of processing and, accordingly, require more specific energy during grinding. When grinding hard and less plastic materials, the growth rate of cracks when cutting with abrasive grains is higher, which reduces energy costs for material deformation. For this reason, hard and less plastic materials require relatively less specific energy for grinding [10].

Finally, let's pay attention to how the change in hardness of the studied material affects its operational characteristics, especially since it is relevant for modern conditions in Ukraine. The main role of the armor plate is to increase the safety of the combatants. Armor plates are made by welding high-hardness armor steel (HHA), but a reduction in hardness may occur. Taking into account the direct correlation between the hardness of armor steel and its ballistic characteristics, avoiding softening becomes important. For this, welding was performed using a flux consisting of nanoparticles of tungsten carbide (WC), titanium carbide (TiC), silicon carbide (SiC) and ethanol. As an example, hardness values of 654.0 HV and 590.4 HV were observed with 8% WC and 8% SiC, respectively, i.e. increases by 16.6% and 5.28% compared to no nanoparticle flow [11]. That is, the use of flux with nanoparticles increases the hardness in the welding zone and the ballistic characteristics of armor steel.

Let's summarize the above.

First, hardness is an important indicator, and in order to improve the operational characteristics of products, one should strive to increase it [5, 11];

secondly, a decrease in hardness improves plasticity, i.e., the transition to the plasticity mode when processing brittle materials is associated with a decrease in their hardness [7];

thirdly, during diamond-abrasive processing, for such transfer to the plasticity mode, it is necessary to increase the grain size of the abrasive and reduce the concentration of abrasive grains in the working layer [9];

fourth, hard and less plastic materials require relatively less specific energy for grinding [10].

3. Formulation of the purpose of the research

That is, the hardness of the processed material is an important factor that affects its machinability and specific energy intensity during grinding. At the same time, in the literature there are no studies of the performance indicators of the diamond abrasive tool during the processing of different tool materials, but with a study of the effect of changing their hardness in a certain range on the same material, which was the goal of this work.

4. Presenting main material

At the same time, an exclusively brittle material (oxide-carbide ceramic VOK60, range of hardness change 82–94 HRA) and conditionally viscous-brittle materials (hard alloy TT21K9, range of hardness change 90.5–92.0 HRA and high-speed steels P18 and P6M5, hardness change range 60–64 HRC). The hardness ranges specified above were determined by the possibilities of selecting a significant batch of samples of one tool material and the presence of a noticeable range of hardness at the same time. It should be noted that it was not possible to achieve this only for hard alloy, but taking into account the large number of hard alloy plates, it was possible to divide them into three sub-ranges according to the hardness of HRA: 90.5–90.9, 91.0–91.5 and 91.6–92.0. At the first stage, deep grinding of high-speed steels with a productivity of 1920 mm3/min was considered. with a cubonite wheel 12A2-45° 150x10x3x32 – KPS 100/80 M1-10 100. Samples 100x20x8 mm in size with a hardness of 60±0.5 and 64±0.5 HRC were pre-selected.

The wear resistance of the grinding tool was studied based on the relative consumption of KNB grains in the wheel during grinding (q, mg/g), and the effective grinding power (N_{ef}, kW) and the specific energy intensity of grinding (E_{pyt}, kJ/kg) were determined. The specific energy capacity of grinding was calculated according to the new method described in the article [12]. The test results are shown in Table. 1.

In our opinion, as the hardness of steels increases, they become less viscous, chips are removed more easily, and therefore both wheel wear and the specific energy consumption of grinding are reduced. Indirect confirmation of this is the fact that in P18 steel, where tungsten is almost 3 times more than in P6M5 steel, fragility is also greater and, therefore, similarly, wheel wear and specific energy capacity are lower than in P6M5 steel (see Table 1).

Table 1 – Grinding indicators of high-speed steels at a productivity of 1920 mm^3/min.

Steel brand	Hardness, HRC	N_{ef}, kW	q, mg/g	E_{pyt}, kJ/kg
P6M5	60	1.8	1.61	106.5
	64	1.8	1.30	86.0
P18	60	1.6	1.01	59.4
	64	1.6	0.86	50.6

At the second stage, grinding of TT21K9 hard alloy was considered at a productivity of 480 mm^3/min with a diamond wheel 12A2-45° 150x10x3x32 – AC4MA 63/50 B1-11П-2 125. Hard alloy samples measuring 16x16x6 mm were, as indicated above, previously divided into 3 groups by hardness. Let's pay attention to the fact that TT21K9 is one of the most difficult-to-machine hard alloys containing (% by volume): TiC – 8.7 and TaC – 12.5. Its standard hardness should be 91 HRA, so even small deviations in the smaller or larger direction, in our opinion, should definitely cause a change in the diamond grinding performance. We investigated the wear resistance of the grinding tool based on the indicator of the relative consumption of diamonds in the circle during grinding (q, mg/g) and determined the effective grinding power (N_{ef}, kW) and the specific energy intensity of grinding (E_{pyt}, kJ/kg). The test results are shown in table. 2.

Table 2 – Grinding indicators of hard alloy TT21K9 at a productivity of 480 mm^3/min.

Range of hardness, HRA	N_{ef}, kW	q, mg/g	E_{pyt}, kJ/kg
90.5 – 90.9	0.95	2.8	304
91.0 – 91.5	1.00	2.4	274
91.6 – 92.0	1.20	1.5	206

From the table 2, it can be seen that a slight decrease in hardness (to 90.5 HRA), relative to the standard 91.0 HRA, slightly increases the wear of the wheel and the energy intensity of processing, while with an increase in hardness to 92.0 HRA, the wear of the wheel and the energy intensity of grinding are significantly reduced. That is, these two conditionally viscous-brittle materials (high-speed steels and hard alloys) react in the same way to an increase in their hardness: wheel wear and specific energy capacity decrease.

At the third stage, we considered the grinding of already extremely fragile oxide-carbide ceramics VOK60 with a productivity of 1750 mm^3/min with a diamond wheel 12A2-45° 150x10x3x32 – AC4 100/80 B1-13 100. Samples of alloy ceramics measuring 12x12x4 mm were previously divided into 4 groups by hardness. We would like to point out that the standard hardness of VOK60 ceramics should be 93 HRA, but in the process of manufacturing these ceramics, we selected samples with an abnormally lower hardness, which made it possible to obtain an additional, quite noticeable hardness range of 82–91 HRA. The wear resistance of the grinding tool was investigated by the indicator of the relative consumption of diamonds in the circle during grinding (q, mg/g) and the effective power of grinding (N_{ef}, kW) and the specific energy intensity of grinding (E_{pyt}, kJ/kg) were determined. The test results are shown in Table. 3.

From the Table 3, it can be seen that with the increase in the hardness of such conditionally exceptionally brittle oxide-carbide ceramics VOK60, both the wear of the wheel and the specific energy intensity of grinding do not decrease, as in the conditionally viscous-brittle materials described above (high-speed steels and hard alloys), but on the contrary, they increase. That is, here, in our opinion, with an increase in the hardness of ceramics, there is no transition to increased fragility and easier material removal, which is indicated not by a decrease, but, on the contrary, by an increase in the specific energy intensity of grinding. At the same time, an increase in the hardness of sludge particles improves their abrasive properties, which is reflected in an increase in the wear of the diamond wheel (see Table 3).

Table 3 – Grinding indicators of oxide-carbide ceramics VOK60 at a productivity of 1750 mm^3/min.

Range of hardness, HRA	N_{ef}, kW	q, mg/g	E_{pyt}, kJ/kg
82 – 83	0.95	1.23	45.8
85 – 88	1.07	1.41	59.1
90 – 91	1.17	1.75	80.2
93 – 94	1.28	1.93	96.8

5. Conclusions

Thus, it is possible to draw the following conclusions from the above.

1. Both conditionally viscous-brittle materials (high-speed steels and hard alloys) react equally to an increase in hardness: wheel wear and the specific energy consumption of their grinding decrease.

2. With an increase in the hardness of such conditionally exceptionally brittle oxide-carbide ceramics VOK60, both wheel wear and specific grinding energy do not decrease, as in conditionally viscous-brittle materials (high-speed steels and hard alloys), but, on the contrary, increase.

3. That is, it is likely that an increase in the hardness of conditionally viscous-brittle materials improves the separation of elementary chips, less energy is needed for their separation and, accordingly, the wear of the wheel and the specific energy consumption of their grinding are reduced. On exceptionally fragile materials (ceramics), with increasing hardness, there is no change in chip removal, but the slurry becomes harder and, accordingly, more abrasive, and, as a result, wheel wear and the specific energy consumption of their grinding increase.

4. The conclusion from the literature that hard and less plastic materials require relatively less specific energy for grinding is confirmed by us when comparing materials of approximately the same hardness (in HRA units), hard alloys and ceramics. In ceramics, the specific energy intensity of grinding is actually four times lower than that of hard alloys.

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Валерій Лавріненко, Київ, Україна, Володимир Солод, Володимир Тищенко, Кам'янське, Україна, Євгеній Островерх, Харків, Україна

ВПЛИВ РІЗНОЇ ТВЕРДОСТІ ІНСТРУМЕНТАЛЬНОГО МАТЕРІАЛУ НА ЗНОС ШЛІФУВАЛЬНИХ КРУГІВ З НТМ ТА ПИТОМУ ЕНЕРГОЄМНІСТЬ ШЛІФУВАННЯ

Анотація. *Для різального інструменту визначальну роль відіграє твердість матеріалу інструменту. Водночас це впливає на їх технологічність, хоча є певні особливості. Так, твердість кераміки на основі нітриду кремнію і карбіду кремнію має менший вплив на їх оброблюваність, ніж щільність, а при шліфуванні загартованих сталей сила різання не залежить від їх твердості. Твердість жароміцних інструментальних сталей визначається дисперсністю і кількістю карбідів, що виділяються при відпусканні, і залишкового аустеніту в якості м'якого компонента. Аж до показника твердості інструментальних сталей 65 HRC, зі збільшенням твердості* *зростає і їх міцність. Однак їх висока твердість відповідає різкому зниженню в'язкості. Саме тому певний інтерес можуть представляти дослідження впливу показника твердості на оброблюваність матеріалу інструменту, коли змінюється твердість на одному матеріалі. Встановлено, що умовно в'язко-крихкі інструментальні матеріали (швидкорізальні сталі та тверді сплави) однаково поводять себе із підвищенням твердості: знос кругу і питома енергоємність їх шліфування зменшуються. Зі збільшенням твердості крихкої інструментальної оксидно-карбідної кераміки, як знос кругу, так і питома енергоємність шліфування навпаки, підвищуються. Тобто, підвищення твердості в'язко-крихких матеріалів полегшує відділення елементної стружки, енергії для цього треба менше і відповідно знос кругу і питома енергоємність їх шліфування зменшуються. На крихкій кераміці зі збільшенням твердості якоїсь зміни у видаленні стружки не відбувається, але більш твердий шлам стає і більш абразивним і, як наслідок, знос кругу і питома енергоємність їх шліфування збільшуються. Висновок з літератури про, те, що тверді і менш пластичні матеріали потребують порівняно менше питомої енергії на шліфування підтверджується нами при порівнянні матеріалів приблизно однакової твердості – твердих сплавів та керамік. У керамік енергоємність шліфування фактично у чотири рази є меншою, аніж у твердих сплавів.*

Ключові слова: *твердість; швидкорізальні сталі; тверді сплави; кераміка; знос шліфувальних кругів з НТМ; питома енергоємність обробки.*