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On the wear comparative analysis of cutting tools made of composite materials based on polycrystalline cubic boron nitride when finish turning of AISI D2 (EN X153CrMoV12) steel

This study presents the results of research on the condition of low content polycrystalline cubic boron nitride cutting tools (cBN-L) when finish turning of hardened AISI D2 tool steel. The least changes in the condition of wedges throughout the investigated turning feeds were observed for the composite cBN020 whereas the highest wear intensity was found for the composite cBN200. For all researched cutting materials, abrasive wear, as well intense adhesion were observed.

***Keywords**: cBN-L, hardened steel, finish turning, wear, cBN coatings.*

INTRODUCTION

Technology advances, both in design and technological solutions, used in machine tools and in modern cutting materials, result in machine parts production. Particularly, it expresses in turning hardened materials rather than grinding them in a conventional manner. As result, a comparable precision of machining is obtained with lower manufacturing costs [1].

The wear of PCBN wedges is one of the most frequent research issues in the area of machining of hardened materials. According to [2–4], two groups of PCBN-based tool materials can be distinguished:

a) Low-cBN (cBN-L), which contains a lower (40–65 %) cBN volume fraction in the tool material, most often with a ceramic binder (e.g., TiC, TiN), typically dedicated to continuous hard machining, usually with single- or multilayer anti-wear coating;

b) High-cBN (cBN-H), which contains a high (70–95 %) cBN volume fraction in the tool material, most often with a metallic binder, recommended for interrupted hard machining.

Due to higher overall thermal and mechanical properties [2], cBN-H tools usually have no anti-wear coatings.

According to [5, 6] the wear progress of coated cBN-L tools is much slower, than of uncoated cBN-L, especially in the case of higher feed rates and higher cutting speeds.

Study [7] presents the results of a comparative research on the wear of cBN-L and cBN-H tools during continuous, semi-discontinuous and discontinuous turning of AISI 4340 (EN 40NiCrMo7) steel hardened to 56 HRC with machining parameters: $v_c = 150$ m/min, $f = 0.05$ mm/rev, $a_p = 0.15$ mm.

At continuous and semi-discontinuous machining, a higher tool life was registered for cBN-L wedges. The cBN-H tools featured better properties in the case of discontinuous machining, which was a direct effect of much higher strength, thermal resistance and ductility of such materials compared to the cBN-L ones. The above research was continued in [8], expanded by a variable turning speed v_c. As machining materials there were used: cBN 7015 with a TiN coating (v_c = 150, 250 m/min) and uncoated cBN 7025 (v_c = 150, 195 m/min). For continuous machining at a low v_c, the main wear factor for the wedges of both types was abrasive wear, while for higher v_c – diffusion wear. For discontinuous machining, intensive abrasive and diffusion wear were observed in both cases, while the wear of flank face for the cBN 7015 was 3 times higher than the one for the cBN 7025.

The study [9] focused on the wear mechanism for both types of material (cBN-H, cBN-L) in the course of turning AISI 52100 (EN 100Cr6) hardened steel. An analysis of the wedge condition showed that the cBN-L tools featured a lesser wear of flank face compared to cBN-H. At the same time, the depth of machining a_p was found to have merely a minor impact on the tool wear.

The wear of cBN-H cutting tools with 6 % cobalt binder was the object of research conducted by more and others in [10]. Crater wear and flank face wear were among dominant types of wear for the tested tools. It was determined that the wear of flank face was caused by abrasive impact of martensite contained in hardened AISI 4340 (EN 40NiCrMo7) alloy.

In his work [11], Arsecularatne researched the condition of PCBN machining tools after turning AISI D2 (EN X153CrMoV12) steel hardened to 62 HRC. The least changes in the condition of cutting tools were obtained for feed rate f in the range of 0.08–0.2 mm/rev and turning speed v_c in the range of 70–120 m/min. It was determined that cutting tools wear the most on their flank faces.

According to [12], the main wear areas for PCBN cutting tools when finish turning of hardened steel included the crater wear of rake face with the simultaneous wear of flank face. Features and intensity of the above types of wear depend on the percentage content and size of cBN crystallites and chemical composition of the binder in the tool material.

Similar conclusions can be found in study [13] in which research results were presented for the wear of cBN-H wedges (88 % cBN of cBN crystallite size 2 µm in metallic matrix) when turning of AISI 4040 (EN 42CrMo4), AISI 5115 (EN 16MnCr5) and AISI A2 (EN X100CrMoV51) hardened steels. The research results indicate that among main causes of wedge wear is diffusion, which is manifested as craters with simultaneous abrasion of the flank face. Chemical composition of the binder was found to be of the crucial significance.

For the tested type of PCBN, the sudden appearance of craters was most likely caused by the solubility of cobalt in iron through reactions with sulphur, due to which the melting temperature of cobalt reduced from 1459°C to approximately 870°C.

Boucher and others in their study [1] researched the wear of PCBN tools when turning of AISI 52100 (EN100Cr6) hardened steel. The results showed that the turning velocity v_c had the highest impact on the blade abrasive wear while the main types of wear included crater wear occurring simultaneously with flank face wear.

In a study [14] Coelho and others investigated the impact of tool coatings on the wear of PcBN blades in the course of machining AISI 4340 (EN40NiCrMo7) hardened steel. Three different types of coating based on TiN and TiC were tested. The analysis of the research results indicated that such coatings acted as a thermal barrier between the contact surface of wedge and cBN crystallites.

According to [15], the coatings of cBN tools increase their chemical stability, thus ensuring a better resistance to adhesive wear. However, the study [16] concludes that the efficiency of the most of coatings is not sufficient today.

Besides the studies and research on increasing stability and decreasing tool wear in the course of machining hardened steel with PCBN tools by depositing of high resistant coatings, extensive investigations of cBN-based composites are fulfilled. One of those, cBN/Si_3N_4, has been made by Bakul Institute for Superhard Materials, National Academy of Sciences of Ukraine [17]. The addition of 10 vol % of silicon carbide SiC to that composite allowed about 20 % decrease of flank face wear when discontinuous turning of EN 107WCr5 steel. Furthermore, it was determined that the composite containing 87 vol % cBN, 3 vol % Si_3N_4, 10 vol % SiC may be recommended as a tool material for this kind of machining [18].

The aim of the present research was a comparative analysis of the PCBN cutting tools condition when finish turning of AISI D2 (EN X153CrMoV12) hardened steel.

CONDITIONS OF RESEARCH

The AISI D2 (EN X153CrMoV1) 2high-carbon high-chromium tool steel was tested, that used for cold pressing works and whose chemical composition is presented in Table 1.

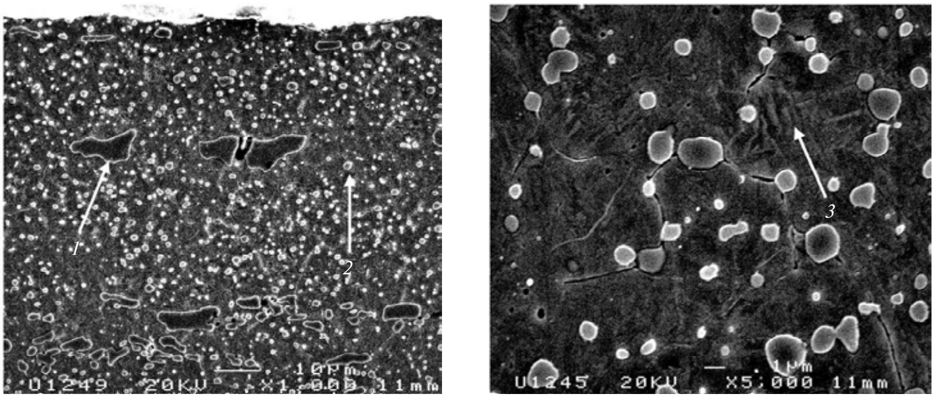
Table 1. Chemical composition of AISI D2 (EN X153CrMoV12) steel

Chemical composition, wt %						
C	Si	Mn	Cr	Mo	V	Fe
1.5–1.7	0.15–0.4	0.15–0.45	11–13	0.7–1.0	0.6–0.8	the rest

Steel samples were hardened and low-tempered, which ensured the hardness of 63±2 HRC. This material structure is characterized by the presence of large primary and secondary carbides created in the course of tempering (Fig. 1, *a*). Their microhardness exceeds the hardness of martensitic matrix of lamellar structure as much as three times (Fig. 1, *b*).

Processing was performed with the following machining parameters: v_c = 160 m/min, a_p = 0.2 mm, f = 0.1, 0.2, 0.3 mm/rev. The PDJNR2020K11 cutter was used in testing with DNGA 110408 inserts and the geometry $\kappa_r = 93°$, $\alpha = 6°$, $\gamma = -6°$, r_ε= 0.8 mm. The cutting material features are presented in Table 2.

A JEOL JSM-400 scanning electron microscope was used for structure testing. The condition of cutting tools before and after turning was assessed with a three-axial optical measuring system Alicona Infinite SL combined with measurement software IFLaboratory Measurement Module. The dry turning conditions were used for testing.



a *b*

Fig. 1. Martensitic structure of the tested material: *1* – primary carbides; *2* – secondary carbides; *3* – lamellar structure of matrix.

Table 2. Materials of cutting wedges

Material type	Turning features	PCBN structure	Coating	Topland sizes	
				BN, mm	GB, degree
cBN 7025	Continuous and semi-discontinuous	60 % cBN in the ceramic binder	None	0.1	20
cBN 7015	Continuous	50 % cBN in the ceramic binder	TiN	0.1	30
cBN 020	Continuous	50 % cBN in the ceramic binder	TiAlN	0.13	25
cBN 8120	Continuous	50 % cBN in the ceramic binder	TiAlN	0.13	25
cBN 200	Continuous	65 % cBN in the ceramic binder	TiAlN	0.12	25

RESULTS OF RESEARCH

The condition of a cBN 7015 wedge after turning at a feed of 0.1 mm/rev is presented in Fig. 2. A groove (*1*) and numerous minor pickups (*2*) can be seen, as well as abrasions (*3*) on the flank face, characteristic of all turning wedges tested.

Figure 3 shows the condition of a cBN 8120 cutting wedge after turning at a feed rate of 0.1 mm/rev. It is characterized by a groove (*1*) of significant sizes and significant pick-ups (*2*) within the cutting edge.

Figure 4 presents the condition of a cBN 7025 cutting wedge after turning at a feed rate of $f_3 = 0.3$ mm/rev. A minor abrasion (*1*) and extensive peak-up (*2*) can be seen on the flank face.

Figure 5 shows the condition of a cBN 200 cutting wedge after turning at a feed rate of 0.3 mm/rev. Numerous chippings (*1*), craters (*2*) as well as significant peak-ups on the flank face (*3*) can be seen.

In the case of the cBN 7025 wedge, at the feed rate of 0.1 mm/rev a minor crater wear was observed.

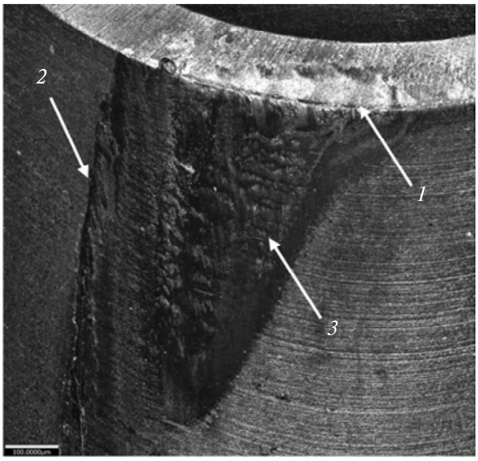


Fig. 2. Condition of cBN 7015 cutting wedge after turning at a feed rate of 0.1 mm/rev: *1* – groove; *2* – adhesive peak-ups; *3* – abrasion on flank face.

Fig. 3. Condition of cBN 8120 cutting wedge after turning at a feed rate of 0.1 mm/rev: *1* – groove; *2* – peak-up on flank face.

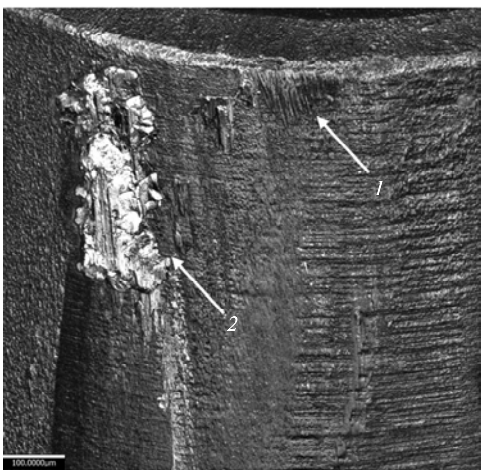


Fig. 4. Condition of cBN 7025 machining blade after turning at a feed rate of 0.3 mm/rev: *1* – abrasion; *2* – peak-up.

At the edge of the cBN 200 cutting wedge one could see numerous chippings of tool material and minor wear in the form of craters. The cBN 020 wedge is characterized by numerous though small chippings and minor abrasive wear tracks. Like cBN 200, wedge discoloration is observed displayed for that material due to the impact of extremely high temperatures at the cutting area.

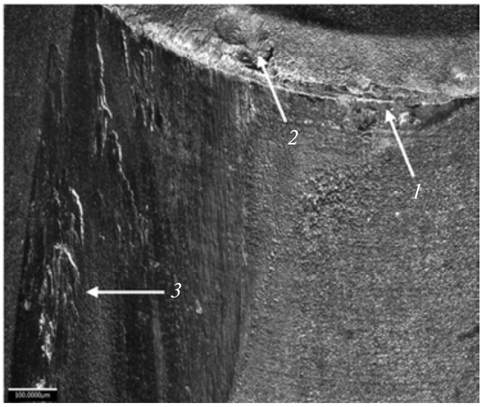


Fig. 5. Condition of cBN 200 cutting wedge after turning at a feed rate of 0.3 mm/rev: *1* – chippings; *2* – craters; *3* – peak-ups.

In cBN 7015 wedge for the feed rate of 0.2 mm/rev a lesser wear was observed than for the feed rate of 0.1 mm/rev. The resulting groove is of much smaller sizes. Minor tracks of abrasive wear were found on the edge. The cBN 7025 tools is characterized by numerous peak-ups, both on the rake face and the flank face, as well as minor abrasive wear. The best wedge condition for this feed rate was is for the cBN 020 tool, which besides changes in the flank face typical of all tested tools, had only minor traces of abrasive wear of its cutting edge.

For the feed rate of 0.3 mm/rev, in cBN 7015 wedge minor abrasions of cutting edge were found and there were numerous peak-ups on the flank face and cutting edge. A heat impact zone was also visible, though its size was much smaller than that observed in the event of turning at a feed rate of 0.1 mm/rev. Similar to turning at a rate of 0.2 mm/rev, the best condition of the cutting wedge was found for cBN 020. Besides changes in the flank face only minor cuts were noticed, caused by machined material contact.

Figure 6 presents abrasion values for flank face named as *VB* parameter. Figure 7 shows the dependence of wedge wear rate $I = VB/t$ as a feed rate f function for the constant turning sped v_c and the depth of turning a_p.

For the range of the feed rates tested, the lowest *VB* parameter and wear rate I values were determined for composite cBN 7015, the only among the tested ones that featured by TiN coating. A significant increase of those parameters according to the feed rate increase was found for the composite cBN 200, which is characterized by highest volume content of cBN crystallites among all tested materials. For cBN 8120 and cBN 020, which have equal top land sizes and the same coating, the *VB* value was decreasing while the feed rate was increasing.

CONCLUSIONS

The detailed analysis was presented in the research which focused on the condition of low content polycrystalline cubic boron nitride cutting tools (cBN-L) when finish turning of AISI D2 (EN X153CrMoV12) steel. For all investigated cutting tools a similar type of wear though different wear rates was determined.

The most frequently occurring wear cause is the abrasive wear observed mainly on the flank faces.

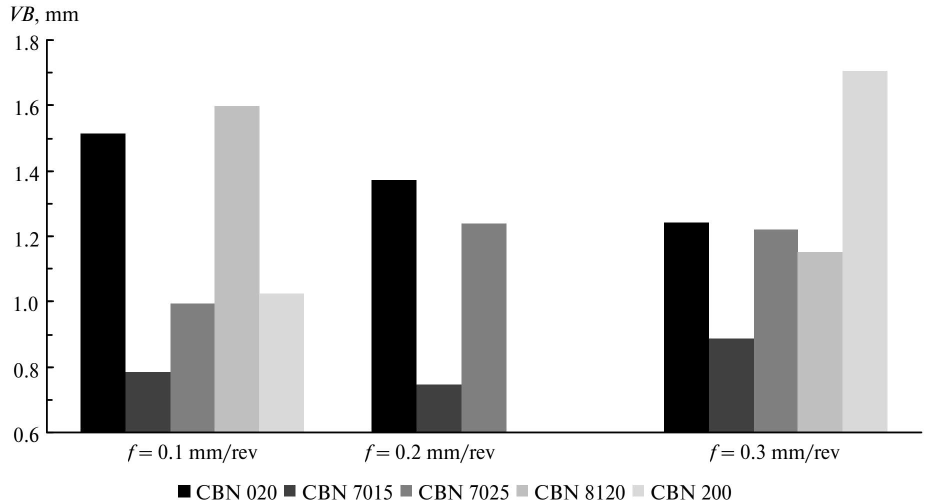


Fig. 6. VB values for tested wedges after turning operation.

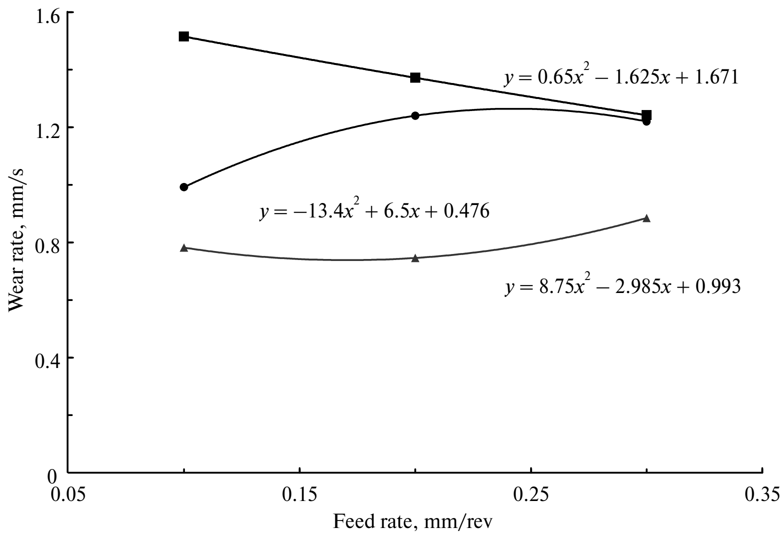


Fig. 7. Dependence of a wedge wear rate on the feed rate: cBN 020 (■), cBN 7015 (▲), cBN 7025 (●).

For the entire range of feeds and for all cutting materials used for the research a powerful impact of adhesive forces was observed, which had the form of accumulation of machined material peak-ups on the flank face. The best condition of the tested tools was determined for the feed rate 0.3 mm/rev. The analysis of the condition of cutting tools shows that the least changes of the wedge condition after cutting with the entire range of feed rates are characteristic for CBN020 material (50 vol % cBN).

The highest wear rate was found for cBN200 material with the highest volume content of cBN (65 vol %), while the lowest wear rate was noted for 7015 material (50 vol % cBN) which, as the only one of the tested tools, had TiN coating.

У даному дослідженні представлено результати досліджень різального інструменту з полікристалічного кубічного нітриду бору (cBN-L) за умови низького вмісту кубічного нітриду бору при обробці загартованої інструментальної сталі AISI D2. Найменші зміни у стані клинів за досліджуваних подач при токарній обробці спостерігали для композиту cBN020, тоді як найвищу інтенсивність зносу виявлено для композиту cBN200. Для всіх досліджуваних різальних матеріалів спостерігали абразивний знос, а також інтенсивну адгезію.

***Ключові слова**: cBN-L, загартована сталь, фінішне тонування, знос, покриттів cBN.*

В этом исследовании представлены результаты исследований режущего инструмента из поликристаллического кубического нитрида бора (cBN-L) с низким содержанием кубического нитрида бора при обработке закаленной инструментальной стали AISI D2. Наименьшие изменения состояния клиньев при всех исследуемых подачах при токарной обработке наблюдали для композита cBN020, тогда как наибольшая интенсивность износа была обнаружена для композита cBN200. Для всех исследованных режущих материалов наблюдали абразивный износ, а также интенсивную адгезию.

***Ключевые слова**: cBN-L, закаленная сталь, отделка, износ, cBN-покрытия.*

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