UDK 621.9

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INVESTIGATION ON WEAR AND TOOL LIFE OF CUTTING TOOLS

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ДОСЛІДЖЕННЯ ЗНОСОСТІЙКОСТІ РІЗАЛЬНИХ ІНСТРУМЕНТІВ
Зношування різального інструменту визначає відвід стружки й стійкість інструменту з погляду економічної ефективності різання. Причина в тому, що надтверді інструменти коштують дорого, а оброблені деталі повинні мати строгі параметри відносно точності і якості. Саме тому дослідження цих інструментів має велике значення. Стаття присвячена деяким особливостям кубічного нітриду бора та інструментів, що впливають на визначення терміну служби інструмента.

Ключові слова: зношування інструмента, термін служби інструмента, інтенсивність зношування

Износ режущего инструмента определяет отвод стружки и стойкость инструмента с точки зрения экономической эффективности резания. Причина в том, что сверхтвердые инструменты стоят дорого, а обработанные детали должны иметь строгие параметры в отношении точности и качества. Именно поэтому исследование этих инструментов имеет большое значение. Статья посвящена некоторым особенностям кубического нитрида бора и инструментов, влияющим на определение срока службы инструмента.

Ключевые слова: износ инструмента, срок службы инструмента, интенсивность износа

The wear of cutting tools is determinant in chip removal and tool life is in economic efficiency of cutting. The reason is that superhard tools are expensive and surfaces or parts machined by them have to fulfill strict requirements referring to the accuracy and quality. That is why investigation on these tools have a major importance. The paper focuses on some wear feature of CBN tools and on determining of tool life.

Keywords: tool wear, tool life, wear intensity

INTRODUCTION

Hard machining is characteristic of the machining of hardened parts with 50-65 HRC hardness. Owing to superhard tool materials in finish machining hard turning more and more comes into view against grinding. The advantages of hard turning are the higher production flexibility, the higher material removal rate, the higher productivity and through all these, the reduction of costs of manufacturing [1, 2]. Despite the machining that uses no CL at all, the produced part has got good surface integrity and roughness appropriate for precision machining. These advantages however return just in case these tool materials ensure the appropriate shape and dimensional accuracy besides optimal tool life. Therefore several researchers deal with the examination of the wear mechanism of CBN tools. The typical CBN tool wear mechanisms are decisively abrasion as well as adhesion and diffusion wear [3]. Several mathematical models have been created to describe these wear mechanisms [4, 5]. The main wear patterns that can be observed on CBN tools are: decisively flank wear as well as crater wear, edge wear, nose wear, chipping, thermal shock cracks [3]. The observed wear patterns are caused by not only one wear process, but the simultaneous appearance of the above mentioned wear processes.

Flank wear is the most reported wear pattern because it is the determinant wear pattern due to the hardness of workpiece, crystal structure, and the particularity of chip removal, and it is used as a tool life criterion. Since the CBN tools are brittle, microchipping and/or tool breakage are typical, which are caused by the increasingly positive rake angle before tool flank wear reaches the pre-specified flank wear criterion. To better predict the tool life, it is recommended to use the crater-wear depth in addition to the flank-wear width as the tool life criteria [3]. It is necessary to take difference between low content CBN tools (CBN-L) and high content CBN tools (CBN-H) in case of wear examination, and between continuous and interrupted cutting in case of determination of wear rate. Tool materials content 50-75 vol.% CBN grains with ceramic binder are noted as CBN-L and tool materials content ~90 vol.% CBN grains with metallic binder are noted as CBN-H [6]. When researchers tested CBN tool wear several surprising phenomena were observed: CBN-L tool materials gave longer tool life, the rate of wear was smaller and the surface quality was better than CBN-H [7]. This is surprising because CBN-H has greater hardness and fracture toughness than CBN-L. There are many different explanations for these puzzling phenomena. Some researchers suggest the longer tool life of CBN-L is due to greater bonding strength, some propose that the welded layers on the tool flank wear land of CBN-L create a protection effect, and others attribute the lower thermal conductivity of CBN-L to the softening of workpieces in the shear zone [7]. Chou et al. have done experiments comparing flank wear land between BZN6000 (CBN-H) and BZN8100 (CBN-L) tool materials in case of machining hardened steels [7]. Chou et al. based on scanning electron micrographs explained that the greater wear resistance of low BN content tools is caused by a transferred layer on the flank wear land. For low BN content tool the transferred layer is smooth and uniform, while the transferred layer on high content BN tools is rough, striated. This is caused by hard wear debris during abrasion and plucked out CBN particles from the tool itself [7]. Many hard machining operations involve interrupted cutting conditions such as gear facing, and spline shaft turning. In these cases the interrupted path of cutting and the high density of load changes make the tool wear more intense [8]. Despite the increased applications, few researchers dealt with the examination of the process. The initial researches focused on brittle fracture and sudden tool failure. Today the tool entry and exit angles, cut and non cut time ratio, thermal cracking, thermal shock cracking and cutting edge effect are examined [8]. Naikai et al. [9] tested various low CBN content tools in interrupted turning of hardened steels and concluded that CBN tools with smaller grain sizes have better wear resistance in interrupted hard turning. This trend is a result of increased hardness and transverse rupture strength by finer CBN grains. Dewes és Aspinwall [10] tested various CBN tools in milling hardened steels. It was reported that CBN-H performed better than CBN-L at high speed range, while at lower speed CBN-L had longer tool life. In addition, it was observed that chipping was a dominant wear mode.

1. EXPERIMENTS TO DETERMINE THE EXTENT OF WEAR

In recent years a lot of new information on hard turning enriched the technical literature [1, 2]. However, to make this advanced finish machining widespread,

further examinations are needed. So, besides the wear mechanisms and their forms of appearance, one of them is the study of the wear intensity of cutting tools to describe the tool life as accurately as possible. Determining the tool life is important for economic analysis and the planning of the technological process of parts alike. We did cutting experiments for hard machining, specifically boring. We chose internal cylindrical surfaces because machining of bores is almost as frequent as that of external surfaces and the tool wear is characterized by more intensive processes than in machining external surfaces. When producing these surfaces, because of their more difficult machining, earlier it was accepted to make concessions for accuracy, surface quality and economic requirements (and/or expectations) as regards to external cylindrical surfaces. These differences are narrowing because of the quality expectations of the product and the economy of production. The other aspect was that in machining holes the chip removal is characterized by more intense processes than in external surface machining. The effect of bore diameter was analysed because due to the geometrical and kinematic relations of chip removal, besides the cutting parameters, the bore diameter also affects the chip removal process [11]. During the experiments we machined internal cylindrical surfaces with different bore diameters with high CBN content tools and determined the relations with which the wear can be characterized.

2. CUTTING EXPERIMENTS

We did the experiments with two CBN tools having different quality and the same tool edge geometry (CBN 1 and CBN 2, the CBN 2 tool's grain size is smaller than 1 μm), with constant feed rate and depth of cut value, with different cutting speeds, while the bore diameter changes were studied. The cutting conditions were as follows:

- cutting tools: CBN 1 and CBN 2,
- tool edge geometry: γ=-5°; α=α'=15°; λ_s=0°; κ_r=45°; κ'_{r1}=2°; κ'_{r2}=15°; b_ε=0.3mm,
- workpiece: hardened bearing steel: 100Cr6 HRC 62±2,
- the examined range of the diameter of workpiece: d=45–100 mm,
- machine tool: E400-1000 universal turning lathe,
- cutting parameters: f=0.075 mm/rev; depth of cut : a_p=0.1mm,
- cutting speed: v_c=11÷120 m/min,
- wear criterion: VB=0.4 mm.

CBN tools wear primarily on the flank surface, and the extent of this wear determines the tool life. The 0.4 mm of dimension of this wear was chosen as tool life criterion. The CBN cutting tools until such value of wear can retain their good cutting ability, the increase of cutting force is insignificant, the roughness of the machined surface is not appreciably worse [11, 12].

During the experiments, we found that the protect layer and metal buildup which appear on the rake face of the tool have a significant impact on the working ability of the tool and they are a phenomenon determining the cutting process basically [12].

3 EVALUATION OF RESULTS

3.1 DETERMINATION OF WEAR INTENSITY

Based on the results of the experiments we the wear intensity of tools was determined. The wear intensity was determined at different cutting speeds from the cutting length values which belonged to a 0.4 mm value of flank wear.

If the wear is counted for a unit of the cutting length one gets the wear intensity (k) [13]. According to this:

$$k = \frac{VB}{L} \tag{1}$$

where:

- k= wear intensity, µm/10^3 m
- VB= flank wear, mm
- L=cutting length, m

The cutting length was determined using

$$L = \frac{C_{T1}}{v_c^2 + C_{T2} \cdot v_c + C_{T3}} \tag{2}$$

relation [14, 15].

The constants were determined by [12].

3.2 CALCULATED RESULTS

The wear intensity and the calculated constants of relation (1) are summarized in Tables 1-3. Figure 1 shows the cutting length. In function of cutting speed, the exact description of cutting length can be determined by equation (2). Figure 2 shows the changing of wear intensity in function of cutting speed.

Table 1 – Wear intensity (CBN 1 tool)

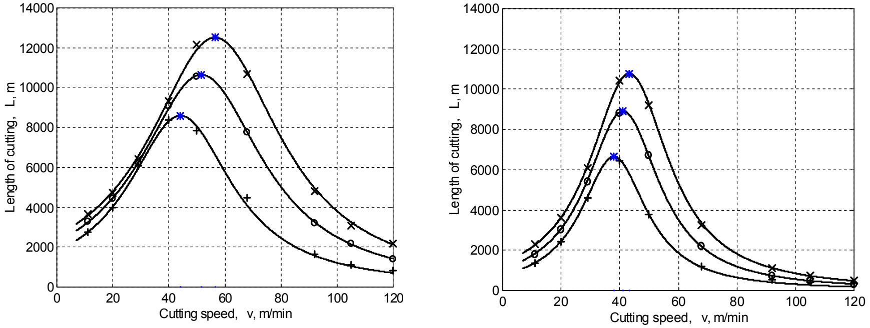
d **mm**	**f** **mm/rev**	**a$_p$** **mm**	**v$_c$, m/min**								
			11	**20**	**29**	**40**	**50**	**68**	**92**	**105**	**120**
			k µm/10^{3}m								
45	0.075	0.1	146	101	66	48	51	89	242	365	481
75			121	90	64	44	38	52	125	186	283
100			110	85	62	43	33	37	84	130	185

Table 2 – Wear intensity (CBN 2 tool)

d **mm**	**f** **mm/rev**	**a$_p$** **mm**	**v$_c$, m/min**								
			11	**20**	**29**	**40**	**50**	**68**	**92**	**105**	**120**
			k µm/10^{3}m								
45	0.075	0.1	302	168	87	63	109	366	1034	1561	2310
75			222	129	72	43	61	183	542	831	1242
100			175	111	66	38	43	123	366	537	846

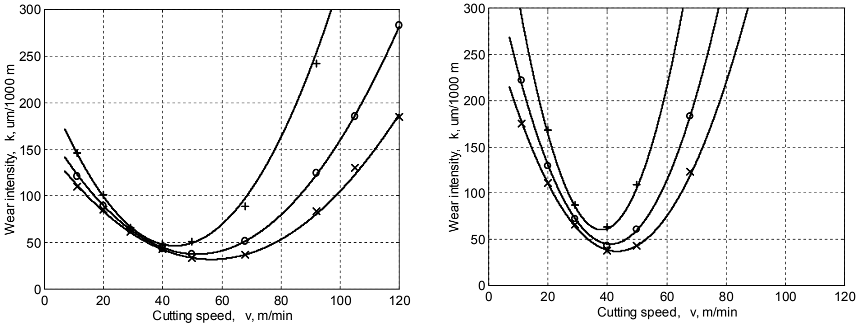
Table 3 – The constants of tool life equation

d	**f**	**a$_p$**	**CBN 1**			**CBN 2**		
mm	**mm/rev**	**mm**	**C$_{T1}$**	**C$_{T2}$**	**C$_{T3}$**	**C$_{T1}$**	**C$_{T2}$**	**C$_{T3}$**
45	0.075	0.1	$4.42 \cdot 10^6$	-88.3	2463	$1.26 \cdot 10^6$	-76.0	1635
75			$7.67 \cdot 10^6$	-103.2	3382	$2.08 \cdot 10^6$	-82.2	1923
100			$10.37 \cdot 10^6$	-113.0	4019	$2.97 \cdot 10^6$	-86.6	2148



CBN 1 CBN 2

Figure 1 – The cutting length at different workpiece diameters +: d=45 mm; **o**: d=75 mm; **x**: d=100 mm (f=0.075 mm/rev.; ap=0.1 mm; VB=0.4 mm)



CBN 1 CBN 2

Figure 2 – Changing of wear intensity in function of cutting speed at different bore diameters +: d=45 mm; **o**: d=75 mm; **x**: d=100 mm (f=0.075 mm/rev.; a$_p$=0.1 mm; VB=0.4 mm)

It can be established from the representation of wear intensity that with the increase of the value of cutting speed, the wear intensity decreases first, reaches a minimum value and then starts to increase. Beside relatively great feed rate in case of CBN 2 tool the wear intensity is smaller in a narrow range. It concerns both the ranges of cutting speed and the ranges of workpiece diameter. Increasing the diameter from 45 mm to 100 mm in case of tools CBN 1 and CBN 2, the maximum value of the cutting length increases by 30 %. Analysing Figure 1 and Figure 2 we can state that in case of different workpiece diameters the character of curves does not change in function of cutting speed. Because of the greater chip deformation and thermal stress, with the decrease of the workpiece diameter, the wear intensity increases and the maximal cutting length together with its cutting speed decrease. The hard turning experiments applied for finish bore machining verify that the CBN cutting tools are characterized by long tool life. Performing the wear and tool life experiments in the usual way, with the suggested and in practice easily applicable relations the tool life path and the values of wear fluctuation can be determined.

4 CONCLUSIONS

The experiments were done with CBN tools (CBN1 and CBN2) with the same tool edge geometry and constant feed rate and depth of cut while we studied the effect of bore diameter at different cutting speeds. Because of the greater chip deformation and thermal stress, with the decrease of the workpiece diameter the intensity of wear increases while the maximal cutting length and its cutting speed are decrease.

When choosing the technological data attention must be paid that the optimal parameters can be reached in a relatively narrow range of cutting speed, and the recommended cutting speed values significantly depend on the values of feed rate, depth of cut as well as the machined workpiece diameter. With the correct choice of cutting parameters the economy of chip removal can be increased significantly.

Acknowledgement

The described work was carried out as part of the TÁMOP-4.2.1.B-10/2/KONV-2010-0001 project.

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Поступила в редколлегию 14.04.2011