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TOOL LIFE OF CUTTING TOOL IN CASE OF HARD TURNING

L. RÁCZKÖVI

Department of Production Engineering, University of Miskolc, 3515 Miskolc - Egyetemváros, HUNGARY
E-mail: laszlo.raczkovi@uni-miskolc.hu

The wear and tool life of tools applied to precision cutting have huge significance, because we perform the finishing of parts with expensive tool materials and the advantageous chip removal properties of these materials are valid in a narrow range of technological parameters. Until recently grinding was used in finish machining; nowadays hard turning is used instead of or in addition to grinding. Grinding requires a lot of cooling and lubricating liquid, whereas hard turning is dry machining, therefore it is very advantageous from the point of view of environmental load.

This paper presents the examination of the wear of PCBN tools and the results of determining the tool life of these tools. The experimental results were processed using the tool life relation, valid in the whole range of cutting speed.

Keywords: PCBN; Cutting tools; Tool life

Introduction

Increasing the lifetime of parts requires the formation of more hard surface. Creating the hard surface of parts needs higher expenditure and more operations, but after tempering, the fatigue limit is also increased in addition to strenght and hardness. Therefore, after the appropriate finishing, the parts are much more chargeable, abrasion-resistant, and the lifetimes will be longer. [1]

The quality of worked parts is influenced by finishing. Working of very hard materials can be finished by grindig, turnig or the combination of the two processes. During manufacturing the requested quality of the part can be achieved by hard turning so that the working process can satisfy certain economic conditions at the same time. The wide-spread use of hard turning requires the more accurate description of the wear and tool life of cutting tools [2, 3, 4]. Determining the tool life is necessary for economic analisys and for creating the mathematical model to specify the cutting parameters. During the cutting process, the cutting tools are subject to wear. The intensity of wear depends on the conditions of the cutting process. Up to the permitted limit of wear – which is called lifetime criterion – the time spent in the process of cutting is the tool life, which depends on the changes of cutting speed. The oldest and still used tool life equation originates from 1901 and it was published in 1904 by F. W. Taylor [5]. Taylor determined the tool life, belonging to the different cutting speeds, with the v_c-T tool life curve ("Taylor curve"). The equation published by Taylor is only valid in a narrow range of cutting speed. This equation is called the simple Taylor equation, differentiated from its later, improved version, which also reflects the effect feed-rate and the depth of cut plays on tool life. The simple and improved Taylor equations can only provide a relatively good approximate on the descending branch of the tool life curve in a narrow range of cutting speed and it can be characterized with a group of straight lines. Clearly, it has a serious practical significance that these equations can take into consideration all of three cutting parameters but the possible extrapolation is very limited. This tool life equation is used most generally in practice because it has a huge experimental database and it can be handled in a simple way [6, 7].

However, it can be noticed that, in a wider range of the cutting parameters, especially the speed of cutting, the tool life which is calculated with the Taylor equation is different from the actual, measured tool life. It is almost natural if we take into consideration that the wear determining the tool life is evolved through a very complicated mechanical-, chemical-, electric-, etc. process. As the conditions of cutting change, the mechanical and heat load of the cutting tool also change, the ratio of the components of wear are modified and their mathematical handling becomes difficult.

Cutting experiments and their results

During the cutting experiments, the surfaces of work-pieces were cut by PCBN hard turning. These surfaces were previously cut with grinding. The experiments designed to determine tool life were accomplished using PCBN tool with different cutting speeds and values of federating and depth of cutting.

The experimental conditions were as follows [8]:
- cutting tool: Composite 01;
- tool edge geometry: $\gamma = -5°$; $\alpha = \alpha' = 15°$; $\lambda_s = 0°$; $\kappa_r = 45°$; $\kappa'_{r1} = 2°$; $\kappa'_{r2} = 15°$; $b_\varepsilon = 0.3$ mm
- workpiece: tempered steel: 100Cr6 HRC 62±2;
- diameter of workpiece: d = 45 mm
- machine – tool: E400-1000 universal centre lathe;
- cutting parameters: f = 0.025–0.125 mm/rev; depth of cut: ap = 0.05–0.25 mm; v_c = 11–120 m/min
- wear criterion VB = 0.4 mm.

Table 1 contains the combination of cutting parameters which was measured the wear of cutting tool [8]. The wear criterion was chosen to 0.4 mm and we measured the tool life along this value of wear.

Table 1: The measured tool life during cutting experiments

f [mm/rev.]	a_p [mm]	Measured tool life T [min]								
		v_c [m/min]								
		11	20	29	40	50	68	92	105	120
0.025	0.1	357	241	230	249	276	220	81	50	33
0.075	0.1	249	198	209	209	157	66	18	10	7
0.125	0.1	203	183	184	167	103	30	8	5	4
0.5	0.05	328	238	246	246	258	142	43	25	19
0.5	0.15	258	194	203	216	216	93	25	14	10
0.5	0.25	229	179	184	202	183	70	18	10	7

Evaluation of the experimental results with new tool life equation

In the cutting process it often means a difficulty that some phenomena change the characteristic of v_c–T curves. The layers with different origin and thickness that appear on the face of the tool (e.g. metallic and non – metallic accumulation) can seriously increase the tool life in a specified range of cutting speed. A wide range tool life experiments proved that the change of real tool life can be described with a rational fractional function of cutting speed (which has the most intensive influence on tool life) with a relative maximum and a relative minimum. [8, 9] We can see from the data of table 1 that the relation between cutting speed and tool life is not monotonous, it can be described with a function which has two extreme values, through which the whole range of cutting speed can be divided into three parts. These three parts are shown in *Fig. 1*. The equation, which is valid in the whole range of cutting speed and suitable to describe the changing of tool life – in other words the tool life equation – is the following [10]:

$$T = \frac{C_{T1}}{v_c^3 + C_{T2} v_c^2 + C_{T2} v_c} \qquad (1)$$

where: T – tool life

v_c – cutting speed

C_{T1}, C_{T2}, C_{T3} – constants depending on the technological conditions of cutting

Based on the measured values, the constants of equation (1) can be determined by regression calculation. The calculation is performed using MathCad software that applies the principle of nonlinear least squares. The software has its own built-in function applying the Levenberg – Marquardt algorithm [11] to minimize the residual error.

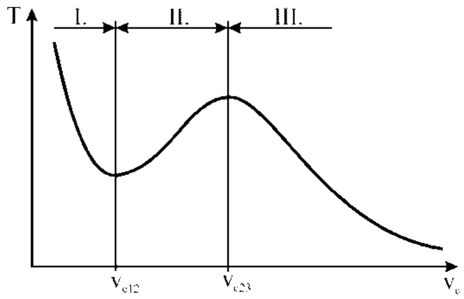

Figure 1: The effect of cutting speed on tool life

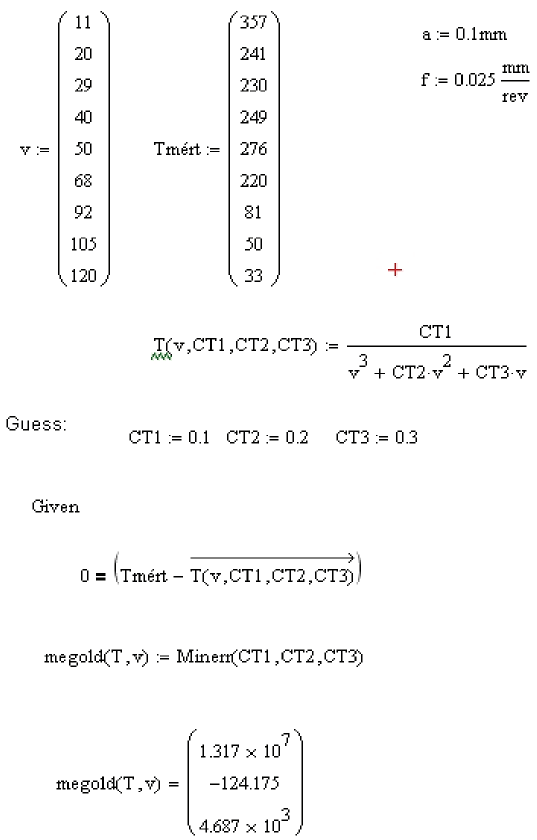

Figure 2: Determining the C_{T1}, C_{T2}, C_{T3} constants with MathCad

The Levenberg – Marquardt (LM) algorithm is an iterative technique that locates the minimum of a multivariate functions, expressed as the sum of squares of nonlinear real-value functions. The application of the software is shown by *Fig. 2* for the highlighted values of Table 1.

The measured tool life points and the calculated tool life curve are shown by *Fig. 3*.

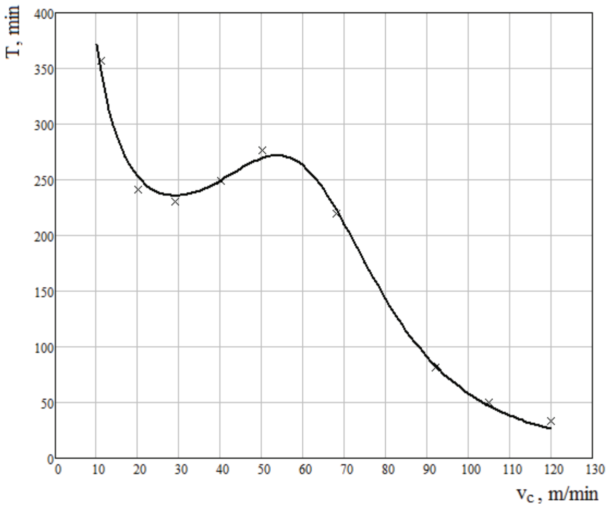

Figure 3: Comparison of the measured tool life points and the calculated tool life curves

We can see from Fig. 3 that the calculated tool life curve well suits the measured points. Applying the calculation to the rest of the given measured values of feedrate and depth of cut, we can determine the sought constants, which are comprised in *Table 2*.

Table 2: The calculated C_{T1}, C_{T2}, C_{T3} constants

f [mm/rev.]	a_p [mm]	Composite 01		
		C_{T1}	C_{T2}	C_{T3}
0.025	0.1	$1.317\cdot10^7$	-124.18	4687
0.075	0.1	$4.422\cdot10^6$	-88.27	2463
0.125	0.1	$2.631\cdot10^6$	-77.50	1893
0.5	0.05	$8.914\cdot10^6$	-106.90	3551
0.5	0.15	$5.784\cdot10^6$	-100.08	3055
0.5	0.25	$4.595\cdot10^6$	-95.32	2777

We described the calculated tool life values, belonging to constant feedrate and depth of cut, on two diagrams depending on which cutting parameter is constant. *Fig. 4* shows the calculated tool life values in case of constant a_p = 0.1 mm depth of cut and different feedrates.

It can be seen from the diagram that as the feedrate is increased, the tool life curve moves downwards, i.e. the tool life decreases. It can also be observed that the local extreme values of the curves move both in the vertical and horizontal direction towards the decreasing values of tool life and cutting speed. Therefore, the effect of increasing feedrate can be compensated by decreasing the cutting speed.

Fig. 5 shows the calculated tool life values in case of constant f = 0,5 mm/rev feedrate and different depth of cut values.

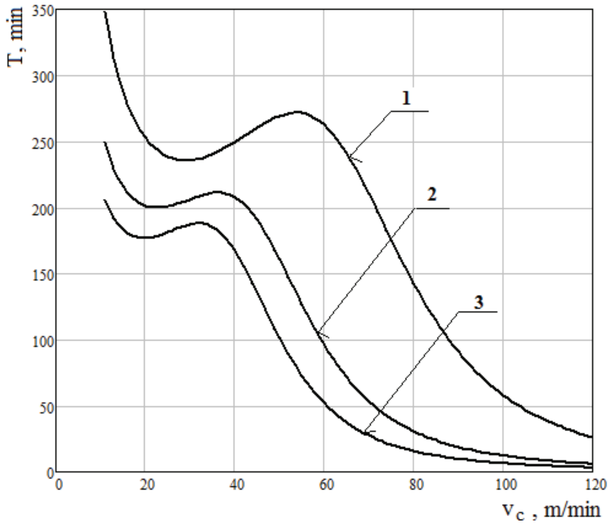

Figure 4: The calculated tool life values with different feedrates

1. f=0,025 mm/rev., 2. f=0,075 mm/rev., 3. f=0,125 mm/rev.

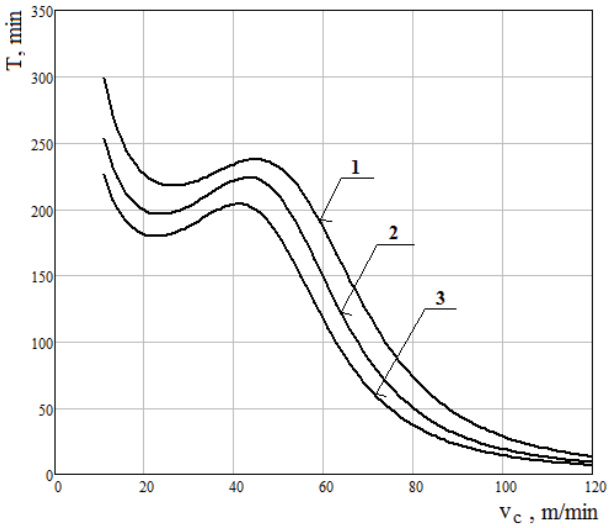

Figure 5: The calculated tool life values with different depth of cut values

1. a_p=0,05 mm, 2. a_p=0,15 mm, 3. a_p=0,25mm.

It can be seen in Fig. 5 that the range bordered by local extreme values is less extended in the horizontal direction, with both extreme values moving in a narrow range of cutting speed. As a result of varying the depth of cut, the curves move in a vertical direction. The effect of increasing the depth of cut cannot be significantly influenced by changing the cutting speed.

Conclusions

The measured tool life values can be evaluated with the chosen relation. The changes that can observed in the whole range of cutting speed in case of cutting with PCBN tools can be described appropriately.

With the help of the MathCad software, we can determine the constants of tool life relation and this way we can predict the tool life in the whole range of cutting speed values.

With the help of calculated tool life curves, it is possible to determine the range of optimal cutting parameters with maximum tool life in case of PCBN tools.

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