RESEARCH PAPERS
FACULTY OF MATERIALS SCIENCE AND TECHNOLOGY IN TRNAVA
SLOVAK UNIVERSITY OF TECHNOLOGY IN BRATISLAVA

2014 Volume 22, Special Number

THE TOOL LIFE OF BALL NOSE END MILL DEPENDING ON THE DIFFERENT TYPES OF RAMPING

Tomáš VOPÁT[1], Jozef PETERKA[1], Martin KOVÁČ[1]

ABSTRACT

The article deals with the cutting tool wear measurement process and tool life of ball nose end mill depending on upward ramping and downward ramping. The aim was to determine and compare the wear (tool life) of ball nose end mill for different types of copy milling operations, as well as to specify particular steps of the measurement process. In addition, we examined and observed cutter contact areas of ball nose end mill with machined material. For tool life test, DMG DMU 85 monoBLOCK 5-axis CNC milling machine was used. In the experiment, cutting speed, feed rate, axial depth of cut and radial depth of cut were not changed. The cutting tool wear was measured on Zoller Genius 3s universal measuring machine. The results show different tool life of ball nose end mills depending on the copy milling strategy.

KEY WORDS

Tool life; ball nose end mill; copy milling

INTRODUCTION

The sculptured surface (free-form surface) machining can be classified as plain cutting, ramping and contouring (1). The most widely used are 5-axis milling centres. Parts are designed in a CAD system. Designing a part according to the application methods is important (2). The program for CNC machine tool is generated in a CAM system (3).

Schulz and Hock (4) used ball end mills with different tilt angles to study tool life and workpiece quality, and they concluded that the down-milling/reverse cut with a tool inclination in the range of 10°~20° represents the optimum machining strategy for high-speed milling in the mould and die making industry.

Chen (5) optimized the tool path of the ball-end milling cutter based on surface error, which is defined by the deviation of the real motion of the tool. The tool path is essential in order to machine an accurate 3D surface. Toh (6) collected the effects of the tool path and orientation to the cutting force, the tool life and surface quality. The path orientation defines the size of the chip contact area and the inclination angle has optimum value from the viewpoint of the tool life. The inclination angle

Tomáš VOPÁT[1], Jozef PETERKA[1], Martin KOVÁČ[1]
[1] Slovak University of Technology in Bratislava, Faculty of Materials Science and Technology in Trnava, Institute of Production Technologies, Department of Machining, Forming and Assembly, Jána Bottu 25, 917 24 Trnava, Slovak Republic
tomas.vopat@stuba.sk, jozef.peterka@stuba.sk, martin.kovac@stuba.sk

in case of free-form surface 3D milling is changed point-by-point but in case of 5D milling it can be constant.

In the experiment, we determined and compared the tool life of ball nose end mill for upward ramping and downward ramping. In this article, equations for calculation of parameters of a hemispherical milling cutter are described.

MATERIALS AND EXPERIMENTAL METHODS

Workpiece material

The selected workpiece material was medium-carbon steel of ISO C45 (AISI 1045) grade. Chemical composition is shown in Tables 1. Block material had dimensions of 100×100×60 mm. Model of workpiece was carried out in CAD system.

CHEMICAL COMPOSITION OF MACHINED MATERIAL C45 Table 1

Element	C	Si	Mn	Ni	P	S	Cr	Mo
wt. %	0.43-0.5	max 0.4	0.5-0.8	max 0.4	max 0.045	max 0.045	max 0.4	max 0.1

Tested cutting tools

Application of ball nose end mill (specimen) is typical for mould milling. It is related to the kinematics representation of ball nose end mill in copy milling. The tested cutting tool material was uncoated cemented carbide (MicroGrain).

We studied two specimens:

S1 solid cemented carbide ball nose end mills for upward ramping (up-copying (7))

S2 solid cemented carbide ball nose end mills for downward ramping (down-copying (7))

Parameters of YG-1 ball nose end mills and are shown in Table 2. Both of them were used for copy milling operations, since we investigated influence of cutter contact areas on the cutter plane on wear of ball nose end mill, which is due to the change of cutter contact area of cutting tool in copy milling operations according to upward and downward ramping.

PARAMETERS OF YG-1 BALL NOSE END MILLS Table 2

EDP No.	Tool Material	Radius of Ball Nose (mm)	Helix Angle (°)	Mill Diameter (mm)	Length of Cut (mm)	Number of Flutes
E5624120	Carbide	R6	30	12	14	2

Tool life test

For copy milling, DMG DMU 85 monoBLOCK 5-axis CNC milling machine was used (Fig. 1a). First, the program for CNC machine tool was generated in a CAM system. Coolant was not used in the machining process. For cutting tests, we set the same cutting conditions (cutting speed, feed rate, axial depth of cut and radial depth of cut). Hence, we intended to investigate just the influence of cutter contact areas on the cutter plane on wear of ball nose end mill for the same cutting parameters. The inclination angle of the workpiece was 15° in the ramping. Tonshoff et al. (8) found that the optimum inclined angle is 15° for ball end-milling of block materials.

Since the flank wear of ball nose end mill was dominant, it was measured on Zoller Genius 3s universal measuring machine (Fig. 1b). The flank wear was measured every 10.75 min equivalent to

2 m length of cut. The machining tests were stopped when the flank wear reached over 0.3 mm or when catastrophic tool failure occurred.

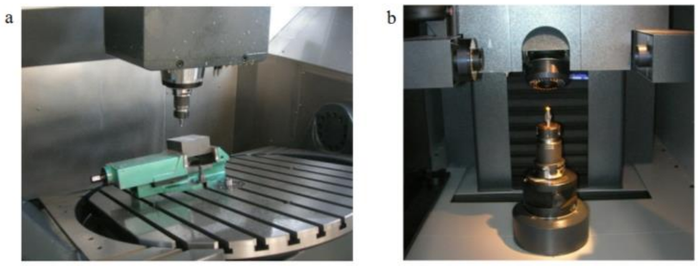

Fig. 1 *(a) Workplace of DMG DMU 85 MonoBLOCK; (b) workplace of Zoller Genius 3s*

Cutting conditions

All tool life tests were carried out with the following parameters: cutting speed v_c = 70 m/min, spindle speed n = 1856.8 1/min, feed rate v_f = 186 mm/min, axial depth of cut a_p = 0.5 mm, radial depth of cut a_e = 0.5 mm, feed per tooth f_z = 0.05 mm.

Effective cutting radius and effective cutting speed in ramping

In upward ramping, tangential curve is placed on the one side from the axis of rotation of ball nose end mill. In downward ramping, tangential curve is placed around the axis of rotation of ball nose end mill on the both sides, and crosses the c enter of rotation of ball nose end mill. The scheme with symbols for ramping is shown in Fig. 2.

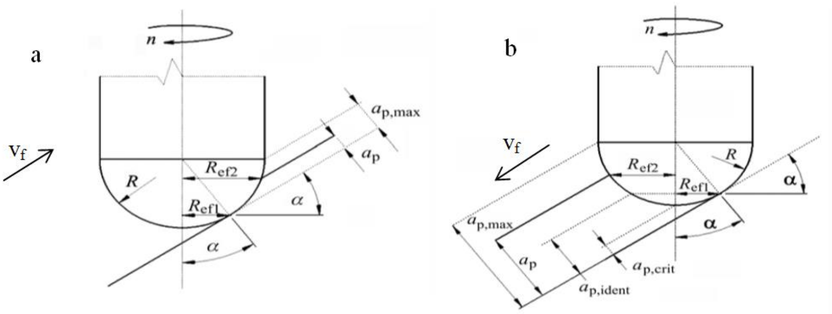

Fig. 2 *(a) Scheme of upward ramping; (b) scheme of downward ramping (9)*

The symbols in Fig. 2:

R - radius of the cutter (mm)
v_f - feed rate (mm/min)
α - slope angle of milling surface (°)
n - spindle speed (1/min)
a_p - depth of cut (mm)
$a_{p,max}$ – maximum depth of cut (mm)
$a_{p,iden}$ - identical depth of cut (mm)
$a_{p,crit}$ - critical depth of cut (mm)
R_{ef1} - effective radius of the cutter on machined surface (mm)
R_{ef2} - effective radius of the cutter on work surface (mm)

Determination of effective radius is very important for obtaining the effective cutting speed. Equations for effective radius and effective cutting speed take the following forms (10):

$$R_{ef1} = R \cdot \sin\alpha$$
$$R_{ef1} = 6 \cdot \sin 15° = 1.55\,mm \quad [1]$$

$$v_{c1} = \frac{2\pi \cdot R_{efi} \cdot n}{1000} = \frac{2\pi \cdot 1.55 \cdot 1856.8}{1000} = 18.08\,m/\min \quad [2]$$

➢ The situations for upward ramping (specimen S1):

$$R_{ef\,2} = R \times \sin\left(\alpha + \arccos\frac{R - a_p}{R}\right) = 6 \times \sin\left(15 + \arccos\frac{6 - 0.5}{6}\right) = 3.74mm \quad [3]$$

$$v_{c2} = \frac{2\pi \cdot R_{efi} \cdot n}{1000} = \frac{2\pi \cdot 3.74 \cdot 1856.8}{1000} = 43.63m/\min \quad [4]$$

➢ The situations for downward ramping (S2) and provided that $a_p > a_{p,crit} \wedge a_p < R$:

$$R_{ef\,2} = R \times \sin\left(-\alpha + \arccos\frac{R - a_p}{R}\right) = 6 \times \sin\left(-15 + \arccos\frac{6 - 0.5}{6}\right) = 0.89mm$$

[5]

From the equation for effective cutting speed results that the highest cutting speed is calculated for the larger of the effective radius R_{ef1} *and* R_{ef2}. Therefore, in upward ramping [equation 3], effective radius $R_{ef2} > R_{ef1}$, the effective cutting speed was calculated for R_{ef2} [equation 4]. Since in downward ramping [equation 5], effective radius $R_{ef2} < R_{ef1}$, the effective cutting speed was calculated for R_{ef1} [equation 2].

RESULTS

Measured flank wear in micrographs

The measured flank wear is shown in Fig. 3a and Fig. 3b. The first two columns are micrographs of flank wear for S1. The other two columns are micrographs of flank wear for S2. Fig. 3a records ball nose end mill before cutting in time of 0 min. Furthermore, Fig. 3b shows measured flank wear after attaining the value of 0.3 mm (in time of 64.5 min for S1 and in time of 86 min for S2).

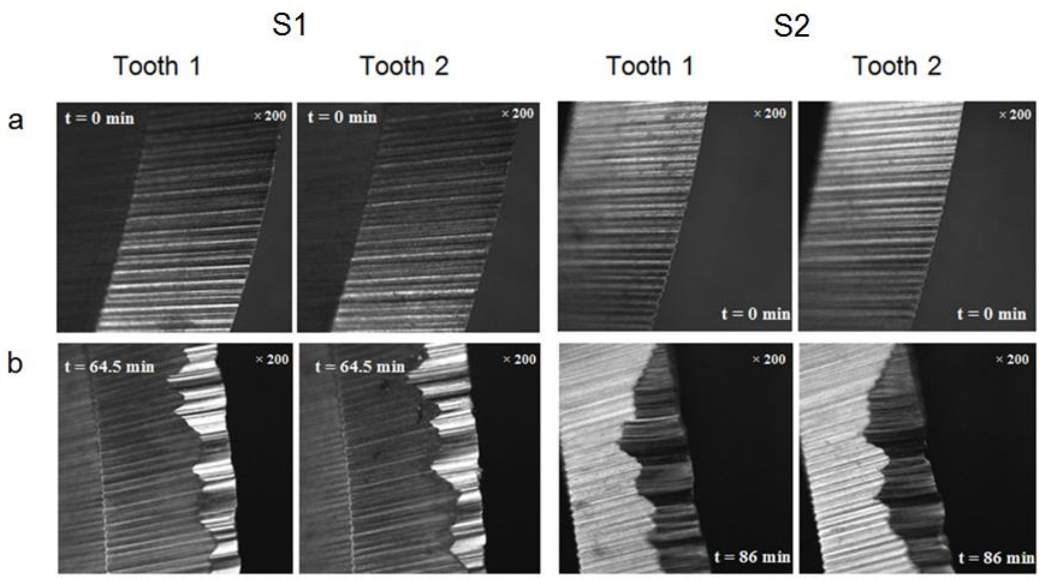

Fig. 3 *(a)Ball nose end mill before cutting,(b)Flank wear after attaining the value of 0.3 mm*

The evaluation of tool life test

The next step of the wear measurement process was evaluation of the tool life test. First of all, the calibration process of measurement system of Zoller Genius 3 was initiated before the milling. The particular wear measurements were implemented for the first and then the second cutting edge. The average value was determined and inserted to Tables 3.

Flank wear values for specimens S1 and S2 are also described in Table 3. For S1, the flank wear value reached over 0.3 mm after 64.5 min of cutting. As can be seen in measurement No. 7, the flank wear value on the second tooth is same as the flank wear value in measurement No. 6. It is caused by the chipping of cutting edge. The flank wear increased, but chipping of cutting edge caused that the measured value of flank wear decreased due to the chipping. For S2, theflank wear value reached over 0.3 mm after 86 min of cutting.

THE MEASURED AND CALCULATED VALUES FOR DIFFERENT TYPES OF RAMPING

Table 3

No.	Time (min)	Length of cut (m)	Flank wear value VB (mm)					
			S1 (upward ramping)			**S2 (downward ramping)**		
			Tooth 1	Tooth 2	Average value	Tooth 1	Tooth 2	Average value
1.	10.750	2	0.062	0.072	0.067	0.070	0.070	0.070
2.	21.500	4	0.111	0.105	0.108	0.100	0.103	0.102
3.	32.250	6	0.170	0.137	0.154	0.140	0.134	0.137
4.	43.000	8	0.229	0.203	0.216	0.178	0.162	0.170
5.	53.750	10	0.280	0.247	0.264	0.220	0.197	0.209
6.	64.500	12	0.302	0.333	0.318	0.264	0.231	0.248
7.	75.250	14	0.374	0.333	0.354	0.298	0.283	0.291
8.	86.000	16				0.344	0.316	0.330

The graph in Fig. 4 plotted based on flank wear value of particular measurement expresses the time dependence of flank wear. The time dependence of flank wear for specimens S1 and S2 was then compared.

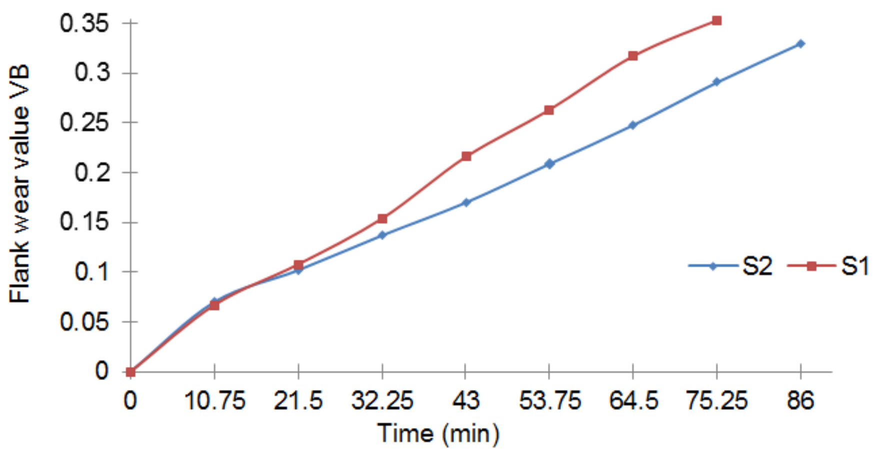

Fig. 4 *The time dependence of flank wear*

As can be seen from the graph, the tool life of S2 is longer than S1. In our case, the tool life of ball nose end mill for downward ramping is 33.33% longer than for upward ramping. We suppose that it is due to various effective radiuses in upward and downward ramping which are mentioned in chapter 1.5. Thus, the effective cutting speed is changed by different effective radius. The effective cutting speed in upward ramping is 2.41 times greater than in downward ramping. The importance of cutting speed can be seen from the Taylor's equation, as the formula relies only on the cutting speed to estimate tool life. Equation [6] is also called Taylor tool-life equation (11). From this equation, it results that the increase of cutting speed leads to decreasing the tool life. From this reason, the tool life of specimen S2 is longer than S1 due to lower effective cutting speed.

$$v_c \cdot T_c^{1/k} = C \quad \Rightarrow \quad T_c^{1/k} = \frac{C}{v_c} \qquad [6]$$

where:
v_c – cutting speed (m/min)
$T_c^{1/k}$ - Taylor's exponent
C - constant.

CONCLUSION

The aim was to determine the tool life of ball nose end mill depending on selected type of ramping. The tool wear criterion was the flank wear value, because it was dominant. We investigated two cutting tools (specimens S1 and S2), which were completely identical. For both cutting tests, we set the same cutting conditions. The worn cutter contact areas of ball nose end mill was first calculated and then observed on Zoller Genius 3s universal measuring machine. For tool life test, DMG *DMU* 85 monoBLOCK 5-axis CNC milling machine was used.

The results showed different tool life for S1 and S2 according to type of ramping. For S1, the flank wear value reached over 0.3 mm after 64.5 min of cutting. For S2, the flank wear value reached over 0.3 mm after 86 min of cutting. The tool life of ball nose end mill for downward ramping (S2) is 33.33% longer than for upward ramping (S1). We suppose that the tool life of specimen S2 is longer than S1 due to lower effective cutting speed during the copy-milling. Hence, selection of downward ramping operation is preferable for copy milling for the case finishing mould, when the tool life is the main criterion. The future study will be complemented by regrinded and honed mills.

ACKNOWLEDGEMENTS

This contribution is a part of the GA VEGA project of Ministry of Education, Science, Research and Sport of the Slovak Republic, No. 1/0615/12 "Influence of 5-axis grinding parameters for geometric precision of cutting shank tool".

This contribution is also supported by the Operational Project Research and Development of Centre of Excellence of five axis machining, ITMS 26220120013, co-financed by European Funds for Regional Development.

REFERENCES

1. C.N. CHU, S.Y. KIM, J.M. LEE. 1997. Feed-rate optimization of ball end milling considering local shape features. *Annals of the CIRP 1997*, **46,** pp. 433–436.
2. JURKO, J., ĎZUPON, M., PANDA, A. et al. 2011. Deformation of material under the machined surface in the manufacture of drilling holes austenitic stainless steel. *Chemické listy*, **105**(S), pp. 600-60.

3. POKORNÝ, P., PETERKA, J., VÁCLAV, Š. 2012. The task of 5-axis milling. Tehnicki Vjesnik - Technical Gazette, **19**(1), pp. 147-150. ISSN 1330-3651
4. SCHULZ, H., HOCK, S. 1995. High-speed milling of die and moulds – cutting conditions and technology. *Annals of the CIRP 44*, pp. 35-38.
5. T. CHEN, P. YE. A tool path generation strategy for sculptured surface machining. *J of Materials Processing Technology*. 2002, **127**, pp. 369-373.
6. C.K TOH. 2004. A study of the effect of cutter path strategies and orientations in milling. *J of Materials Processing Technology*, 2004, **152**, pp. 346-356.
7. SANVIK, Coromant. Contouring or copy milling. http://www.sandvik.coromant.com/en-gb/knowledge/milling/application_overview/profile_milling/contouring_or_copy_milling/pages/default.aspx
8. H.K. TONSHOFF, J. HERNANDEZ-CAMACHO. 1989. Die manufacturing by 5 and 3 axes milling. *Journal of Mechanical Working Technology*, **20**, pp. 105-119.
9. C.C. TAI, K.H. FHU. 1994. A predictive force model in ball-end milling including eccentricity effects. *Int. J. Mach. Tools Manufact*. **34**, pp. 959–979.
10. PETERKA, J. 1997. Analysis of the geometry and kinematics of copy milling. In: *Vedecké práce (Science Theses) MTF STU in Trnava*, 5, pp. 53- 58.
11. International Organization for Standardization. Tool-life testing with single-point turning tools, 1993. ISO 3685