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FLANK WEAR AND SURFACE ROUGHNESS IN END MILLING OF HARDENED STEEL

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This study examines flank wear and surface ruoghness in up and down hard end milling. After obtaining the mathematical models, it has been carried out a series of numerical simulations with variation of input parameters in order to analyze their influence on flank wear and surface roughness. Additionally, flank wear and surface roughness has been analysed in correlation with the volume of the removed material for different cutting parameters. Observed from the viewpoint of machinability, down hard milling is favorable compared to the up hard milling.

Keywords: flank wear, surface roughness, regression analysis, material removal volume

INTRODUCTION

Advances in cutting tool and machine tool technologies have a great impact on the development of new methods of machining. An example of this is a hard milling as a relatively recent technology that can be defined as a machining operation using tools with geometrically defined cutting edges. The values of workpiece hardness are in the 45 HRc - 70 HRc range. There are numerous advantages in hard machining over traditional methodology based on finish grinding operationsafter heattreatment of workpieces. These advantages are: greater part geometry flexibility, reduction of cutting forces [1], surface quality [2, 3], machining ability in only one fixture and using only one machine tool and the possibility of cutting fluid elimination [4, 5]. The main drawback is a high amount of heat generated in hard machining process, as compared to that in conventional machining, which causes the rapid tool wear. The need to explore the factors influencing the economics and product quality in hard machining, leads the research to the extensive assessment of surface product integrity, tool properties, dynamics of the machine tool, and so forth. This paper presents a research work of up and down hard end milling. After the analysis of experimental data, discussion is focused on the flank wear and surface roughness and their relationwith volume of removed material.

EXPERIMENTAL WORK

The end milling experiments were conducted on CNC vertical machining centre, Spinner VC560, equipped with a 12 000 rpm electrospindle and the SK 40 tool holder. Workpiece material, steel 42CrMo4, was prepared for milling operations in the form 250 mm × 110 mm × 110 mm blocks and adapted to the experiment needs. The cutting tool was end mill CoroMill R390-02A20-11M produced by Sandvik. The insert was carbide coated with highly resistant TiAlN coating, Grade Coromant GC1030. Tool wear was measured by means of toolmaker's microscope with 100 x magnification and USB camera. Surface roughness was measured by means of profilometer Mitutoyo Surftest 301.

CUTTING CONDITION AND EXPERIMENTAL DESIGN

One of the main tasks of machine tools is to enable performing of machining operations with the necessary rigidity, to take over the vibrations and to provide the necessary power for machining operations. All of the above depend, among other things, on the workpiece and tool material, the tool geometry and applied cutting parameters: cutting speed (v_c), feed per tooth (f_t), axial and radial depth of cut (a_p, a_e). Guidance on the selection of cutting parameters range, such as recommendations of the tools manufacturer and existing databases were not fully satisfactory.

Extensive preliminary tests for up and down hard milling which determine threshold values of cutting parameters and tool wear criterion, have been performed. Preliminary tests showed that the time required to reach the flank wear criterion is about 22 minutes, depending on the cutting parameters. In all experiments axial depth of cut was constant, 5 mm. All experiments were conducted without cutting fluid and every experiment was performed with new inserts. Time of inserts engagement is taken as the fourth independent variable.

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The experimental design for four input factors with three leveles are organized by rotatable central composite design (RCCD). The 4-factorial RCCD of experiment requires a total of 30 experiments [6]. The input factors and their levels are given in Tables 1 and 2. In order to collect data for analysis of variance and regression analysis software package Design-Expert was used.

Table 1 **Physical and coded values of input factors, down hard milling**

Input factors						
Physical parameters	v_c / m/min.	45	70	95	120	145
	f_t / mm/tooth	0,02	0,05	0,08	0,11	0,14
	a_e / mm	0,5	1	1,5	2	2,5
	t /min.	4	10	16	22	28
Coded parameters		-2	-1	0	1	2

Table 2 **Physical and coded values of input factors, up hard milling**

Input factors						
Physical parameters	v_c / m/min.	45	70	95	120	145
	f_t / mm/tooth	0,005	0,02	0,045	0,07	0,095
	a_e / mm	0,5	1	1,5	2	2,5
	t/min.	4	10	16	22	28
Coded parameters		-2	-1	0	1	2

RESULTS AND DISCUSSION

Applying analysis of the variance and regressional analysis on the experimentally determined data, the regression coefficients were obtained and thereby the regression equations for the flank wear and surface roughnes too. After omitting the insignificant factors, the equations are defined as:

VB / mm, for down hard milling:

$$\mathrm{VB} = 0,15225 - 0,000716v_c - 3,28325f_t + 0,056855a_e - 0,004t + 16,40278f_t^2 + 0,00016t^2 - 0,0003v_c a_e + 0,000035v_c t + 0,047847f_t t - 0,00225a_e t \quad (1)$$

VB / mm, for up hard milling:

$$\mathrm{VB} = 0,17867 - 0,00181v_c - 0,54483f_t + 0,0241a_e - 0,010298t + 0,0000098v_c^2 + 9,58333f_t^2 + 0,010958a_e^2 + 0,00049t^2 + 0,000026v_c t - 0,325f_t a_e + 0,0296f_t t - 0,00289a_e t \quad (2)$$

Ra / µm, for down hard milling:

$$\mathrm{Ra} = 0,13021 + 1,31019f_t + 0,37717a_e - 0,02461_t + 0,000046v_c^2 + 74,88426f_t^2 + 0,00118t^2 - 0,0875v_c f_t - 0,0729f_t t - 0,0077a_e \quad (3)$$

Ra / µm, for up hard milling:

$$\mathrm{Ra} = 2,92638 - 0,041985v_c - 16,825f_t - 0,48125a_e - 0,0296t + 0,00023v_c^2 + 255,16667f_t^2 + 0,20792a_e^2 + 0,000021t^2 - 0,000237v_c t + 0,1625f_t t + 0,00646a_e t \quad (4)$$

After obtaining the mathematical models, it has been carried out a series of numerical simulations with variation of important input parameters in order to analyze their influence on output values. 3D surface plots for flank wear and surface roughness were shown in Figure 1. Flank wear increases with increasing cutting

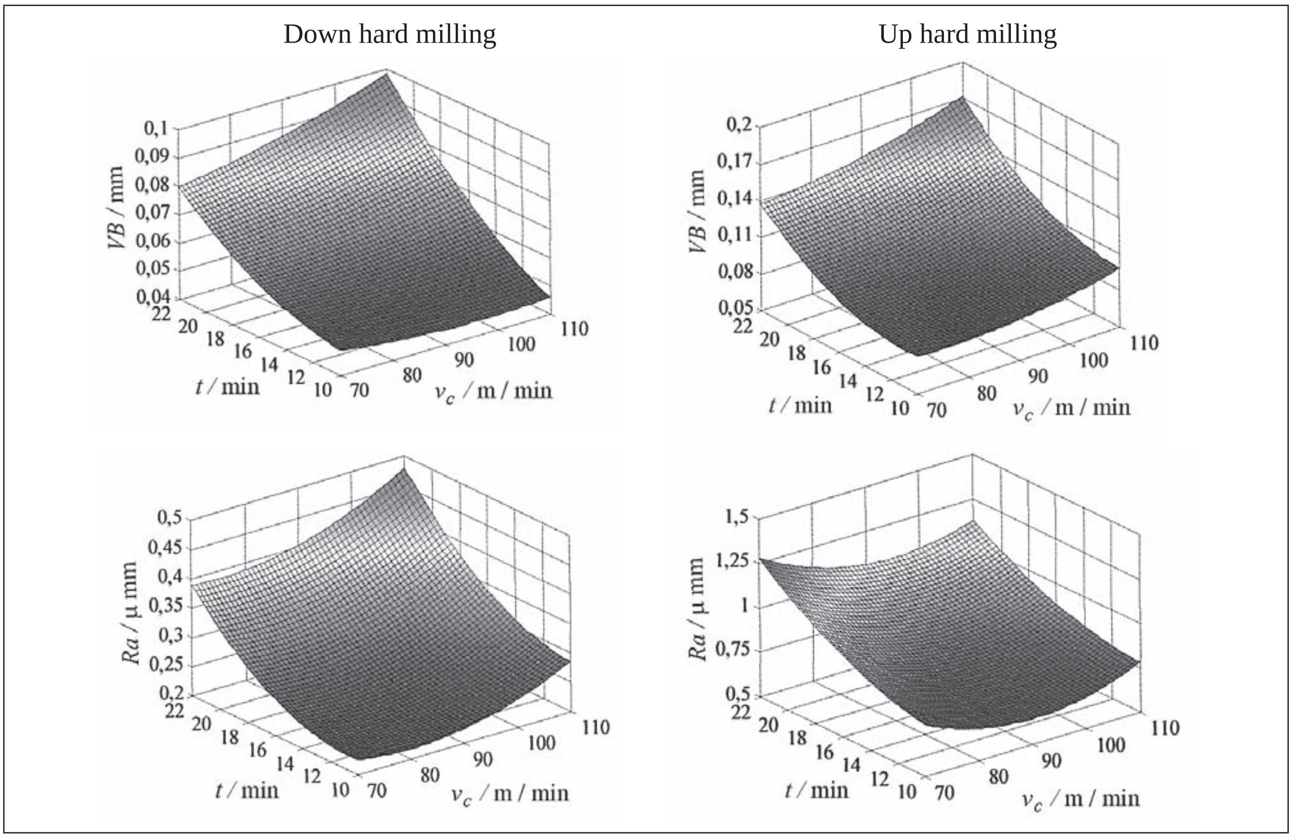

Figure 1 Influence of cutting speed and insert engagement time on flank wear and surface roughness at constant depth of cut a_e = 1,5 mm and feed per tooth f_t = 0,05 mm/tooth

speed and insert engagement time, and the increase is more intenseat higher cutting speeds. Increasing of the flank wear has a consequence in an increase insurface roughness. For the same cutting parameters, down hard milling provide up to 50 % better quality of machined surface than the up hard milling.

In the up milling, cutting edge gradually enters into the workpiece material and slides over the surface of workpiece material. Before the removing, the workpiece material is compressed and the first cracks occur as well. As a result, the temperature in the cutting zone is increased and this leads to intensify all forms of tool wear, and there are also new wear forms, such as diffusion wear. The chip formation in down milling is opposite to the chip formation in up milling. The cutter edge begins to mill the full chip thickness. Then the chip thickness gradually decreases. Since there is no sliding or upsetting of workpiece material, the treated surface is smooth and has better quality, and there are no negative impacts on the flank wear.

ANALYSIS OF FLANK WEAR AND SURFACE ROUGHNESS BASED ON THE REMOVED MATERIAL VOLUME

Volume of the removed material, V / cm^3 is expressed by equation:

$$V = \frac{a_p \cdot a_e \cdot f_t \cdot v_c \cdot z \cdot 1000}{\pi \cdot D_c} \qquad (5)$$

where z is a number of teeth, D_c / mm is a mill diameter.

Figures 2 and 3 show plots of flank wear for two different cutting speeds and feeds per tooth against removed material (V), for down and up hard milling, respectively. The radial and axial cutting depth are constant, 1 mm and 5 mm, respectively. In down hard milling, Figure 2. b), graphs are significantly shifted to the right in relation to the graphs in Figure 2. a). This means that at higher cutting speeds it is possible to remove the larger amount of material before achieving the critical values of flank wear. If one compares the dependence of flank wear of the amount of removed materials for different feeds per tooth, it is obvious that the machining process is not economically viable at higher cutting speeds and low feed per tooth. When considering these cutting parameters, removed quantity of material is insignificant, and the flank wear has reached a critical value.

Flank wearin uphardmilling, Figure 3, is at low feed per tooth values, rapid compared to removed (minor) volume of material. When machining is performed with greater values of cutting speed and feed per tooth, it is

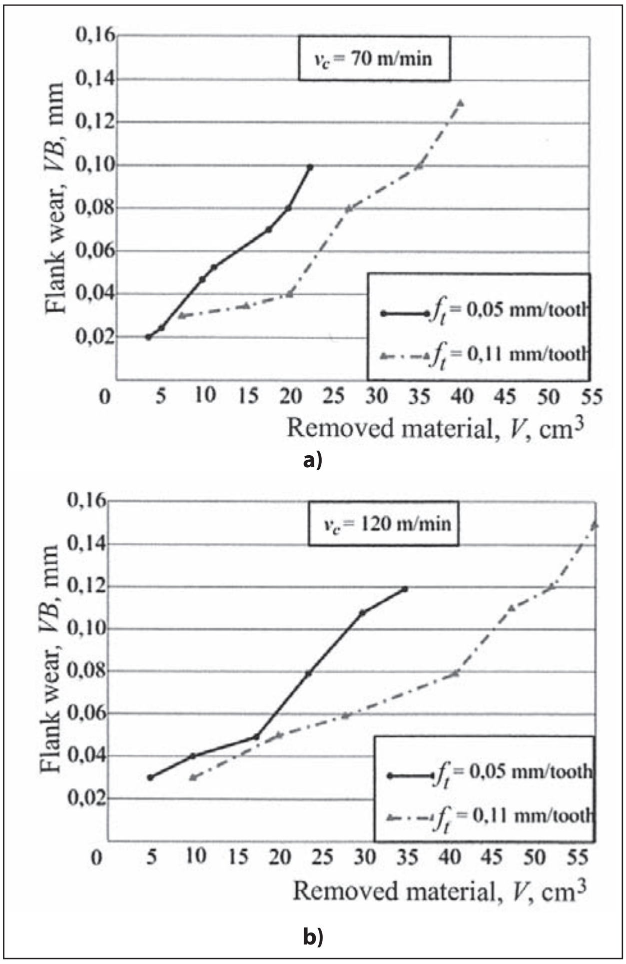

Figure 2 Flank wear progression, down hard milling

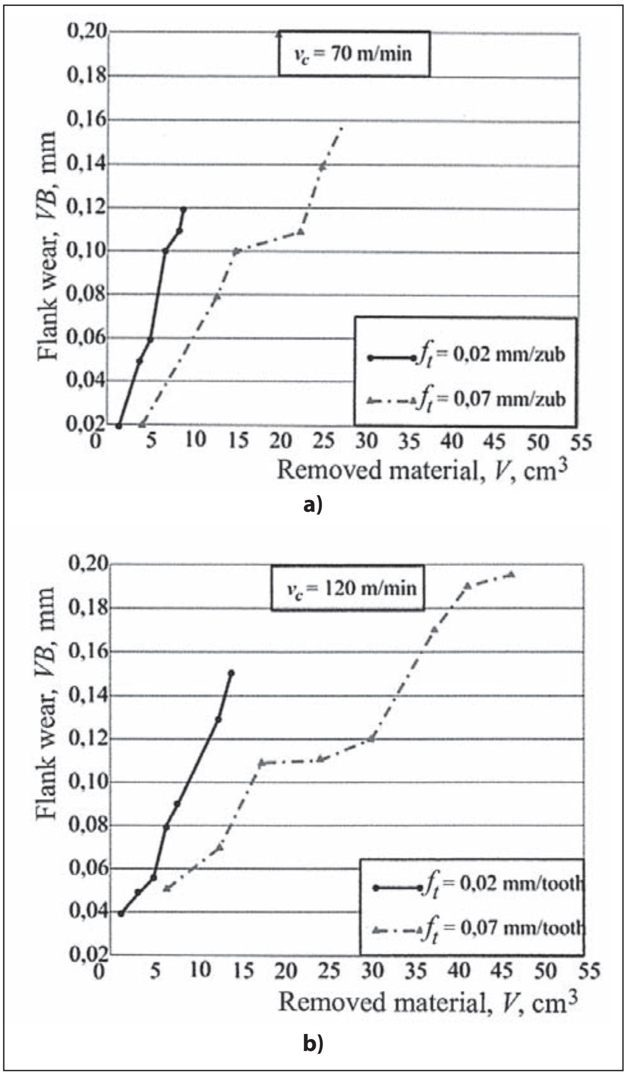

Figure 3 Flank wear progression, up hard milling

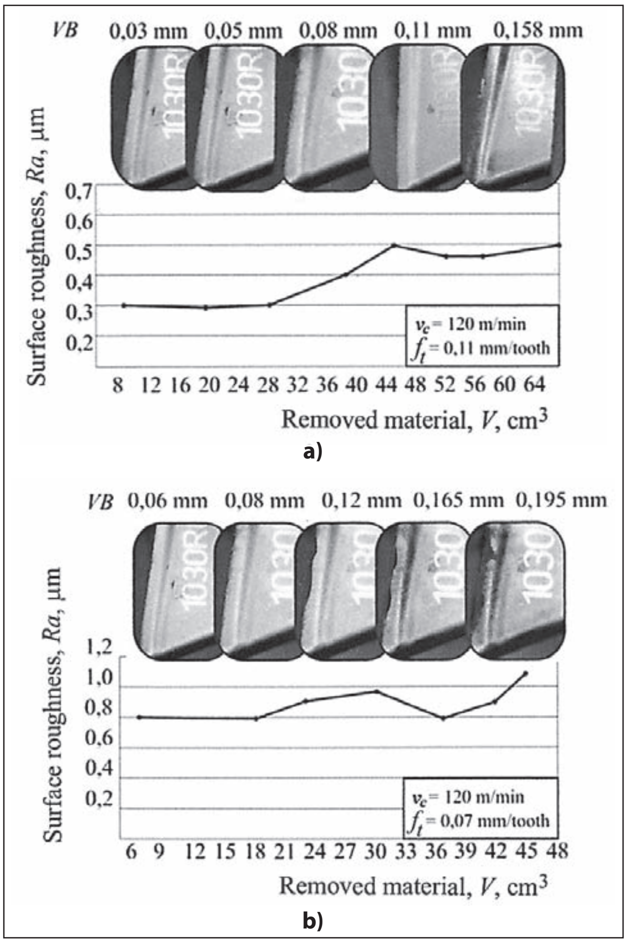

Figure 4 Surface roughness and flank wear progression, down (a) and up hard milling (b)

possible to achieve reasonable amount of removed material thanks to the inserts coating of TiAlN, which has an excellent mechanical properties.

In order to illustrate a relation of flank wear and surface roughness at the same amount of removed material, experimental results can be expressed as shown in Figure 4. Surface roughness and flank wear were measured at equal time intervals. Figure 4. a) shows increasing of flank wear and surface roughness during down hard milling, at cutting speed of 120 m/min and feed per tooth of 0,11 mm/tooth. Surface roughness here shows variability, but remains below 0,5 µm. In the case of up hard milling, Figure 4. b) surface roughness shows also variability but remains about 0,8 µm to 1 µm.

CONCLUSIONS

In this study the influences of cutting speed, feed per tooth, radial depth of cut and time of inserts engagement on flank wear and surface roughness in peripheral milling process have been examined. Observed from the viewpoint of removed material together with flank wear and surface roughness, down hard milling is more favorable compared to the up hard milling. In the presented case, the material removal rate in down milling is greater than in up milling. All of the above contribute that the down milling process performed on CNC machine tool is more effective than up milling.

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Note: The responsible translator for English language is Jasna Vujčić, College of Slavonski Brod