

# Flank wear as a function of cutting time

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**Abstract:** *The paper describes one teaching unit - tool wear, which is studied at laboratory classes in the Metal cutting technology course. Through laboratory classes, students gain practical knowledge. The main goal of this teaching unit is to help students to understand the wear process and to define the parameters that describe the wear process. The most important wear parameter is the width of the flank wear of the tool. By monitoring the changes in the values of this parameter, students can see how the wear process is progressing over time. An end mill was taken as an example. The width of the flank wear was measured at intervals of 5 minutes, at distances of 0.1 mm. Based on the measured values, a diagram of tool flank wear was created. Also, the change in the width of the flank wear depending on the cutting time is shown.*

**Keywords:** *flank wear; end mill; cutting time*

## 1. INTRODUCTION

During cutting, the tool wears out and loses its cutting capabilities, so wear is one of the most negative phenomena in machining processes. Tool wear is a normal phenomenon in the machining process, but is a detrimental factor that affects the quality and tolerance of machined parts [1]. Relatively high pressures and high temperatures on the surfaces of coupled pairs (tools, chips, cutting surfaces), as well as high relative speeds of coupled pairs represent the basic conditions for the occurrence and intensive development of the tool wear process. The consequence of the development of the wear process is the deformation of the cutting elements of the tool, which makes it harder for the cutting wedge to penetrate the material. The wear generally occurs over time and is a gradual failure in a cumulative process that affects tool life. Tool wear will also vary depending on tool geometry, depth of cut, cutting fluid and cutting speed [2].

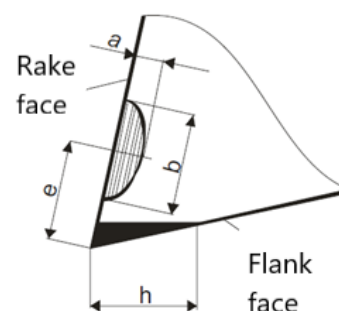
### 1.1. Tool wear and the wear curve

The departure of the particles of the tool material with the chip, the machined surface and the cooling and lubricating agent leads to a change in the shape of the cutting wedge of the tool. This change is manifested through the appearance of: a crater on the rake face and a flank wear on the flank surface of the cutting wedge of the tool.

The three basic forms of wear of cutting tools are:

- wear exclusively on the rake surface of the cutting wedge of the tool in the form of a crater. It is characteristic for machining with high-speed steel tools without the use of cooling and lubricating agents,

- wear exclusively on the flank surface of the cutting wedge of the tool in the form of a flank wear of appropriate width. It is characteristic for the final machining and
- general form of wear (Fig. 1) (wear both on the flank and on the rake surface of the cutting wedge of the tool). It is characteristic for machining brittle materials, steel prone to deposits, machining with greater cutting depths and when applying cooling and lubricating agents, etc.

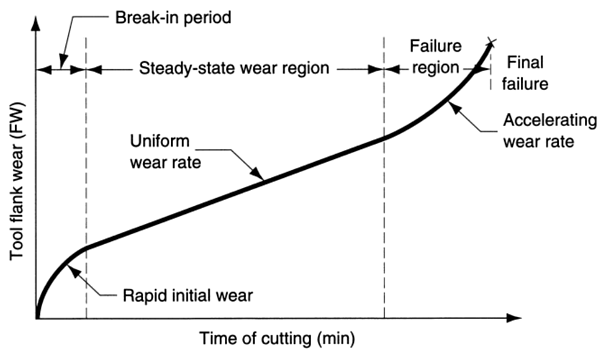


**Figure 1.** *General form of wear [3]*

A crater of certain depth  $a$  and length  $b$  appears on the rake surface, Fig. 1. The center of the crater is away from the cutting edge by a distance  $e$ . Wear on the flank surface appears in the form of a wear zone - flank wear of a certain width  $h$ . During cutting, there is a change in the size of the width of the wear zone, as well as a change in the position and depth of the crater. This means that in order to define and determine wear size, it is necessary to know these basic parameters ( $a$ ,  $b$ ,  $e$  and  $h$ ).

The width of the flank wear  $h$  is the most important parameter for evaluating the wear of the tool. It is directly measured on the flank face of the cutting wedge of the tool. Based on this parameter, a wear

curves are created and the durability of the tool is defined.

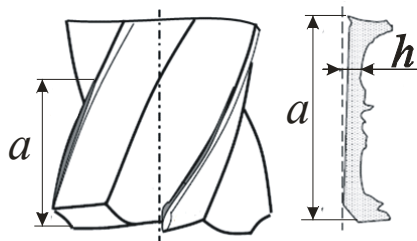


**Figure 2.** Tool wear as a function of cutting time [2].

Flank wear of a cutting tool is known to have detrimental effects on part surface integrity including surface finish, residual stress, microstructure alternations, etc. Flank wear is commonly thought to result from abrasive wear of the cutting edge against the machined surface and has been used to specify the tool life [4].

### 1.2. End mill wear

In order to determine the wear of the tool during the cutting time, the wear of the tool was monitored on the flank face, because in the case of end mill, pronounced wear occurs on the flank face. With these end mill tools, the chip thickness is relatively small, so the friction on the rake face of the cutting wedge is less pronounced. Hence, the formation of craters on the chest surface of the cutting wedge is insignificant [5]. Fig. 3 shows the wear of the flank face of the end mill.



**Figure 3.** End mill wear [5]

## 2. EXPERIMENTAL INVESTIGATIONS

30CrNiMo8 steel (Č 5432, AISI-u 4340), with dimensions 50x30x7 mm, was used as the workpiece material.

During the investigations, high speed steel end mill, DIN 844-A10-K-N prečnikadiameter  $\varnothing 10$  mm (Fig. 4) was used. Characteristics of this end mill are:

- number of teeth  $z = 4$ ,
- cutting angle  $\chi = 30^\circ$ ,
- flank angle  $\alpha = 6^\circ$ ,
- rake angle  $\gamma = 12^\circ$ ,
- twist angle  $\omega = 30^\circ$ ,
- material: high-speed steel (HSS).



**Figure 4.** End mill DIN 844-A10-K-N

The investigations were performed on a vertical milling machine "Maho 600C" (Fig. 5), manufactured by the German manufacturer Maho, with the following characteristics:

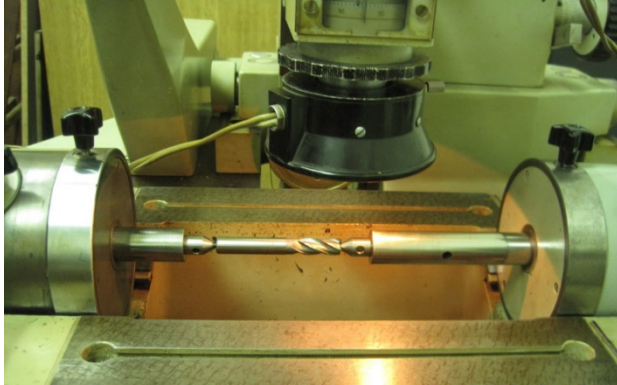
- electric motor power for main movement 5.5 kW,
- electric motor power for auxiliary movement 2 kW,
- number of revolutions of the main spindle 10  $\square$  3150 rpm with 4 gears,
- speed of auxiliary movement 0  $\square$  3000 rpm with 4 gears,
- maximum table load 1000 kg,
- the largest movement of the table in the direction:
  - x-axis 600 mm,
  - y-axis 500 mm,
  - z-axis 450 mm,
- the possibility of turning the spindle axis up to  $90^\circ$ .



**Figure 5.** Vertical milling machine Maho 600C

Machining was performed with the following regimes: cutting speed  $v = 17.28$  m/min, i.e.

number of revolutions  $n = 550$  rpm, feed per tooth  $SZ = 0.045$  mm/z and cutting depth  $a = 1$  mm. No cooling or lubricating agent was used during machining. In order to measure tool wear, the cutting process was interrupted every 5 minutes of machining. The total time for which tool wear was measured was 25 minutes.



**Figure 6.** Postavljanje alata na mikroskopu

Tool wear was measured on a universal electronic microscope of the brand CARL ZEISS JENA, Fig. 6.

**Table 1.** Flank wear – measured values

x [mm]	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
5 min	0.166	0.102	0.096	0.073	0.05	0.076	0.069	0.065	0.066	0.101	0.052
10 min	0.172	0.112	0.105	0.078	0.064	0.08	0.071	0.069	0.074	0.105	0.064
15 min	0.175	0.122	0.108	0.083	0.074	0.083	0.08	0.077	0.08	0.109	0.072
20 min	0.184	0.136	0.11	0.086	0.097	0.086	0.09	0.099	0.085	0.111	0.081
25 min	0.188	0.139	0.114	0.09	0.103	0.105	0.098	0.099	0.115	0.116	0.091

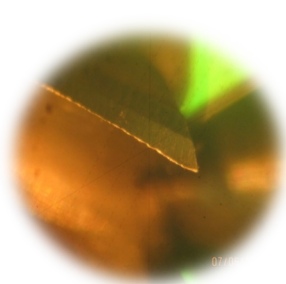
After every 5 minutes of machining, photos of the flank face of the end mill cutter were taken.

On this microscope, rotating samples can be measured by placing them between auxiliary spikes whose range is up to 700 mm. The measurement range is from 0-200 mm and the reading accuracy is 0.001 mm. The mean value of the width of the flank wear was monitored on the flank face of the end mill tool.

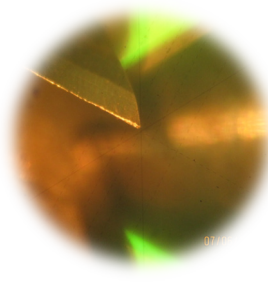
### 3. THE RESULTS OF THE EXPERIMENTAL INVESTIGATIONS

The width of the flank wear was measured on the flank face of the end mill tool at time intervals of 5 minutes during machining. Measurements were made at distances of 0.1 mm. The width of the flank wear was measured on the flank face of the end mill tool at time intervals of 5 minutes during machining. Measurements were made at distances of 0.1 mm, in the direction of the cutting depth, starting from the tip of the tool. The results obtained in this way are given in Table 1. The last measurement was made after the end mill had been cutting for 25 minutes.

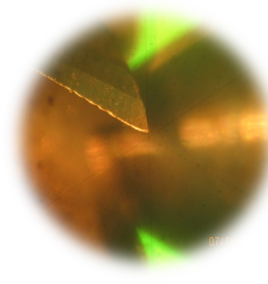
Appearance of a worn milling cutter in time intervals is shown in Fig. 7.



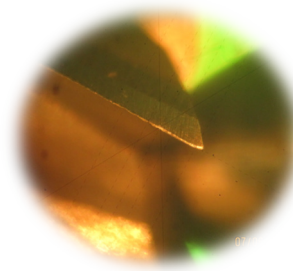
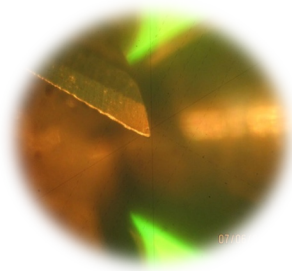
1) The appearance of a worn end mill cutter after 5 minutes of machining



2) The appearance of a worn end mill cutter after 10 minutes of machining



3) The appearance of a worn end mill cutter after 15 minutes of machining



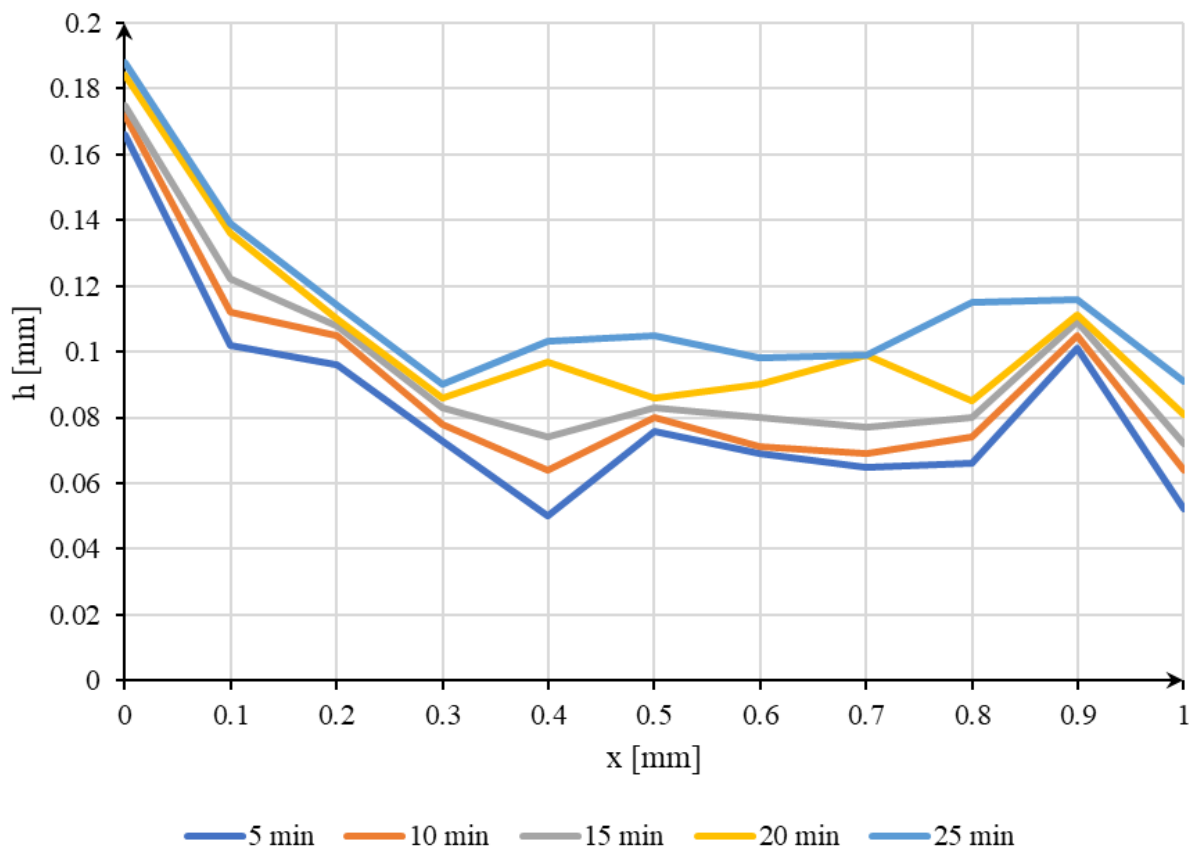
4) The appearance of a worn end mill cutter after 20 minutes of machining

5) The appearance of a worn end mill cutter after 25 minutes of machining

**Figure 7.** Worn end mill

Based on the measurement results given in Table 1, a diagram of the change in the width of the flank wear is given in Fig. 8.

The width of the flank wear was measured every 0.1 mm in direction of the cutting depth ( $a=1$  mm), x-axis.



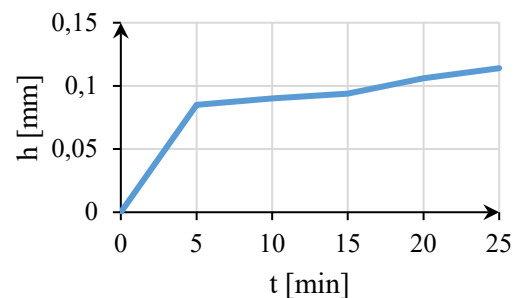
**Figure 8.** Flank wear width as a function of position of measurement and time

For each time interval, the mean value of the flank wear width was calculated. These results are given in Table 2.

**Table 2.** Mean flank wear width

$t$ [min]	0	5	10	15	20	25
$h$ [mm]	0	0.085	0.09	0.094	0.106	0.114

Fig. 9 shows the appearance of the flank wear curve of a end mill cutter.



**Figure 9.** End mill flank wear curve

#### 4. CONCLUSION

By analyzing the obtained results, it is observed that the greatest width of the flank wear is at the tip of the end mill cutter, and then it decreases by about 50% of the value. The width of the flank wear width is almost unchanged right up to a distance from the tip of the tool equal to the depth of cut, when a slight increase in the width of the flank wear width, notch wear, appears. At a distance from the tip of the tool greater than 1 mm, no tool wear was observed. Also, it is observed that with the increase in cutting time, the width of the flank wear increases. By analyzing the diagram of the flank wear curve, it can be concluded that in the first interval of 5 minutes the intensity of flank wear is the highest. This period can be interpreted as a period of rapid initial wear. In this interval, the mass of the cutting tool, that is in contact with the workpiece, is relatively small, so intensive wear occurs. After this period, the flank wear curve has a slower growth and it is the period of uniform wear.

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