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INFLUENCE OF TEMPERATURE ON FLANK WEAR OF CUTTING TOOLS WITH A CUTTING EDGE

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Abstract: The central element of this study was to carry out experimental investigations that allow the study of the influence of the temperature developed in the cutting area on the flank wear of the cutting tools with a cutting edge. The experiments were carried out on the longitudinal roughing turning of a work piece product, made of 40Cr10 steel, intended for the manufacture of brake discs for motor vehicles. The experimental strategy involves performing four turns made on the same machine, with the same type of cutting tool and under the same cutting conditions (without cooling), maintaining the same feed and the same cutting depth for four different cutting speeds. The results highlight how the temperature developed in the cutting zone influences the flank wear of the cutting tool.
Keywords: temperature, wear, flank, tool, speed

1. INTRODUCTION

Metal cutting is the essence of today's civilization because it leads to the production of various parts for a large number of industries [1]. Currently, machining occupies the first place in obtaining parts, due to the machining precision, the diversity of shapes and machined surfaces [2]. The need for performance of the machining process has led to the development of machining systems and to the diversification of methods and procedures for controlling machining results [1]. The process performance is the result of the interaction between the shape and properties of the blank, the geometry of the cutting tool, the characteristics of the machine tool, as well as the cutting conditions adopted. Regardless of the performance of the machining methods and processes, the interaction between these elements leads to damage or wear of the cutting tool, [3]. Damage to the cutting tool involves either breaking the cutting edge or breaking it completely. This phenomenon is to be avoided because it affects the efficiency of the machining process, the safety of the operator and the quality of the machined part. The wear of the cutting tool is a phenomenon that occurs due to the mechanical, thermal, chemical and tribological loads developed during machining [4]. The factors influencing the wear of the cutting tool have a direct influence on its service life. These factors refer to: the material of the work piece being machined through its mechanical and thermal properties, the material and geometry of the cutting edge and the parameters of the cutting regime, [2]. By increasing the intensity of wear, the durability of the cutting tool decreases. Increasing its durability can be achieved by addressing two categories of problems, the first category refers to the design, execution and choice of the cutting tool in the process, and the second to its exploitation [5]. In the context of machining, cutting can be carried out with cutting tools with a single cutting edge or with more than one. Cutting tools with a single cutting edge are used in turning operations [6]. The performance of the cutting tool is dictated by the cutting edge. The main characteristics of the cutting edge refer to: the shape and geometry of the edge, the shape and positioning of the seating face and the clearance face, the properties of the material from which it is made and the coatings applied to it [3], [4]. In the specialized literature there are many works in which the wear of cutting tools has been determined by several methods.

In the paper [7] a new, unitary methodology for measuring flank wear on lathe tools was proposed, because in the case of wear of cutting tools, the international standard ISO 3685/1993 (revised in

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2017) regulates the notations and characteristics of lathe tools wear, but not the measurement methodology. Within the proposed methodology, the increment of measurements was optimized and the measurement errors of the human operator were identified.

Kwon Y. et al used a novel approach in the study of the wear index of the cutting tool (TWI) and developed a model of its service life by analyzing wear surfaces and material losses using micro–optical analysis and image processing–analysis algorithms. The conclusions of the study show that by knowing the wear index it is possible to determine the wear conditions more precisely and comprehensively, and the model of the tool life allows its maximum use, minimizing the risk of failure during the machining process [8].

In the paper [9] the wear mechanisms of the cutting tool during turning were investigated, determining the intensity of its wear. Also, the evolution of the cutting forces according to the parameters of the turning regime was analyzed. Finally, several experimental parametric models were obtained that allow the prediction of the evolution of tool wear, as well as cutting forces, depending on the parameters of the cutting regime.

In the paper [10] a model for predicting the wear of the cutting tool is developed based on the experimentally measured values and the multiple regression analysis. Influencing factors that were taken into account in the study were: machine tool spindle speed, feed speed, cutting depth and workpiece hardness. The material subjected to the experiment was hardened 42CrMo4 steel to which orthogonal turns were applied with carbide plate lathe tool coated with several layers TiAlN/TiN.

Özel et al [11] investigated the influence of cutting parameters on flank wear and machined surface roughness in finish turning of hard steel. Crater and flank wear of ceramic cutting tools is observed using scanning electron microscopy (SEM). The models developed for the prediction of flank wear and surface roughness were performed using linear regression and neural networks.

In paper [12] the authors proposed a new online approach to determine whether cutting edges of cutting tools can be resharpened or are disposable, depending on their level of wear. The study is based on computer vision and machine learning, the proposed method consists of going through three stages: dividing the image from the cutting tool into different regions, characterizing each region in terms of wear using texture descriptors based on different variants of local binary models and finally the decision was made on the cutting edge if it is still functional or disposable.

Choudhury and Rath [13] have shown that tool wear can be correlated with the parameters of the cutting regime and the cutting force coefficient with a maximum deviation of 8% between the experimental and analytically results.

Nouari and Molinari [14] investigated the wear of uncoated tools during the machining of low–alloy steel (AISI 4140). The conclusions of the paper show that the main influencing factor on diffusion wear is the contact temperature. The temperature field was simulated using the finite element method.

The main objective of the work is to study the influence of temperature in the cutting area on the flank wear of cutting tools with a cutting edge. In the work, experimental investigations will be carried out that allow the study of the influence of the temperature developed in the cutting zone on the flank wear of lathe tools, which perform longitudinal roughing turning on the surface of a work piece using different parameters for the cutting regime.

2. DESCRIPTION OF THE PROBLEM

Research has shown that cutting tool wear is caused by a combination of several mechanisms.

Among the mechanisms involved are: abrasive wear, adhesive wear, diffusion wear, oxidation wear and erosive wear [6], [15]. These wear mechanisms can occur simultaneously or one of them can dominate the cutting process, resulting in the appearance of several types of wear on the same cutting tool [7], [16]. The total wear of the tool can be considered as the sum of the effects of the wear mechanisms previously presented, depending in part on: the characteristics of the tool material, the external loads that require the cutting tool and the temperature in the cutting area, Figure 1, [3], [4].

Looking at Figure 1, it can be seen that adhesive wear has a strong effect at relatively low temperatures of the cutting process. When intensifying the process, it is observed that there is a temperature range in which total wear is dominated by diffusion–based wear and, to a certain extent, chemical wear. As the temperature in the cutting area rises above 850^{0}C, all the wear mechanisms intensify [3], [4]. Wear leads to changes in the geometry of the cutting tool. These geometric changes affect both the machining results, in terms of tolerance and quality of the machined surface, and the performance of the cutting tool, [3].

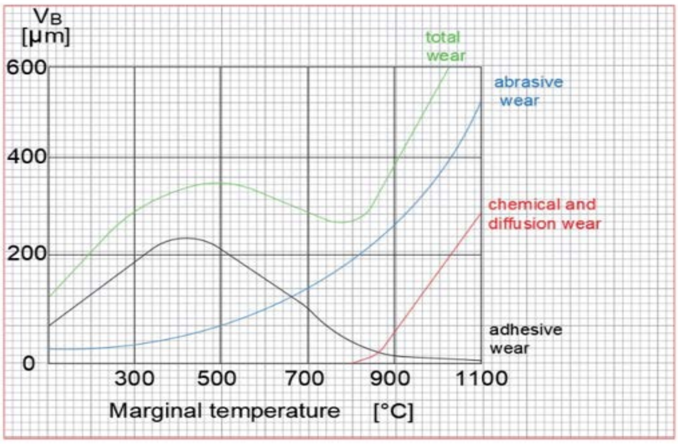


Figure 1. Total wear of the cutting tool as the sum of the effects of different wear mechanisms

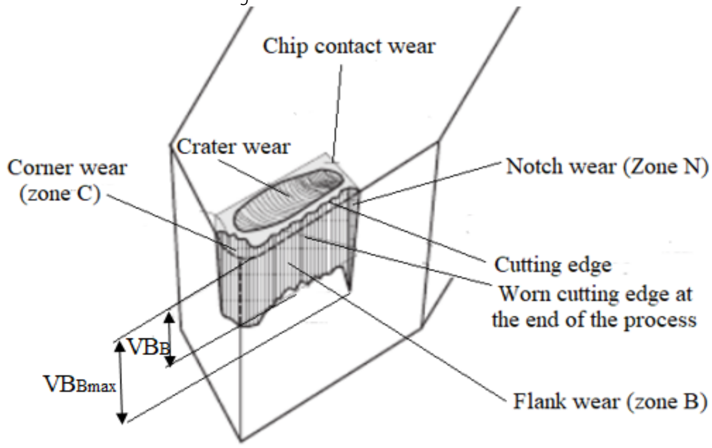


Figure 2. Types of wear on the surfaces of cutting tools with a cutting edge

According to the ISO 3685:1993 standard, cutting tool wear can be divided into the following categories: corner wear, flank wear, notch and crater wear, [3], [6], [7], [10], [17].

As a result of tribological processes taking place in the cutting area, the first three types of wear occur on the seating surface, at the point of contact between the cutting tool and the workpiece, while crater wear develops on the clearance surface in the contact area between the tool and the chip, Figure 2, [1], [7].

The assessment of the wear of cutting tools is based on wear criteria. The wear criterion indicates the extent to which a geometric change in the cutting edge is accepted, [17].

The most widely used criteria for assessing the wear of cutting tools are [17]:
— flank wear, when wear is evenly distributed on the seating face;
— average flank wear along the cutting edge line, when there are local occurrences in flank wear;
— crater wear that appears on the clearance face.

For the purpose of measuring wear, the worn part of the cutting edge is divided into three zones [1], [6], [7]: corner wear (Zone C), flank wear (Zone B) and notch (Zone N), Figure 2.

The durability of the cutting tool is evaluated based on two parameters measured in zone B: VB_{MAX} representing maximum wear, and VB_B indicating average wear.

Flank wear is caused by friction between the surface of the tool and the surface of the workpiece and leads to wear of the cutting edge. Therefore, flank wear affects the dimensional accuracy and quality of the machined surface. In practice, flank wear is the most widely used criterion for assessing the wear of cutting tools, [3].

In the specialized literature, various values for admissible wear can be found, varying depending on the machining process, the type of cutting tool and the cutting edge material [1], [10], [17].

Thus, flank wear is the criterion used to determine the optimal moment to stop the machining process and represents the effective cutting time until the occurrence of admissible wear, i.e. it dictates the life of the cutting tool, [1], [7], [8].

3. EXPERIMENTAL DETERMINATIONS

The experiments were carried out on a universal lathe SNB 400 x 2000 mm, with a power of 7.5 KW, without cooling, and the work piece subjected to processing is made of steel, 40 Cr10, with an initial diameter of Ø50mm and a length of 300 mm. Each machining was carried out with a new lathe tool, made of high–speed steel, with dimensions 20x20 mm and P30 plate, at each processing the turned length being 150 mm. Figure 3 shows the work piece and the lathe tool positioned to begin machining.

Figure 3. Aspects from the beginning of the processing

Figure 4. Monitoring the evolution of cutting tool wear

The values of the cutting regime parameters used in the experiments were chosen as a result of the literature review and in accordance with the available machine tool machining possibilities. The four turns were carried out successively on the same work piece.

Initially, a roughing turning of the bar with a diameter of Ø50 mm on a length of 150 mm was carried out with a speed of n_1 = 31.5 rpm, at the end of the processing the diameter obtained was measured with a digital tool and the real cutting speed was determined. The second turning was carried out on the same work piece with a new tool, the starting diameter being 43.98 mm, the speed being n_2 = 63 rpm, the diameter at the end of the processing was 37.01 mm; at the third turning, the speed was n_3 = 125 rpm, and the diameter resulting was 30.11 mm; the previous procedure was repeated for the last turning achieved with speed n_4 = 250 rpm. The parameters of the cutting regime are shown in Table 1. In this table, the calculation relationship of the cutting speed was:

$$v = \frac{\pi \cdot d \cdot n}{1000} \quad (1)$$

In which: d– the diameter of the work piece at each turning, [mm];

n – lathe spindle speed [rpm].

Table 1. Parameters of the cutting regime

No. Crt.	Cutting depth t [mm]	Feed f [mm/rot]	Spindle speed [rpm]	Diameter D [mm]	Cutting speed v [mm/min]
Tool 1	3,5	0,075	31,5	50	4,948
Tool 2			63	43,98	8,704
Tool 3			125	37,01	14,533
Tool 4			250	30,11	23,648

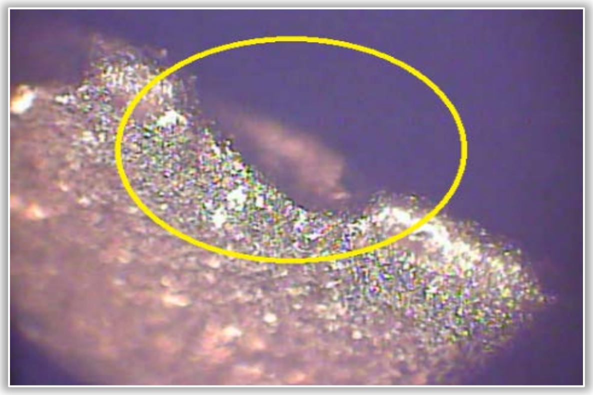
After each experimentation, the flank wear ($V_{B\ max}$) was determined for each tool. The evolution of tools wear during testing were monitored using an optical interface microscope, A–KTUSS OPTRONIC with maximum magnification of 100X and USB kit for computer connection that allows large–scale image presentation, Figure 4.

Determination of flank wear

In order to determine the flank wear, the methodology presented in works [1] and [7] was adopted, which propose an incremental measurement of it on the seating face of the cutting edge. Figure 5 shows the images visualized under the microscope for the four tools at the end of the experiments.

n =31,5 rot/min

n = 63 rot /min



n =125 rot/min

n = 250 rot /min

Figure 5. Visualization of flank wear at the end of the process

Applying the wear determination methodology to the seating face for the four tools led to the results presented in Table 2. This table shows that for experiments 1 and 2 the maximum and average wear values are much lower than the admissible values. For experiment three, both values of wear are at the limit of admissible values. This results implies that the three tools have not exceeded their service life and they can be resharpened for further use.

The highest wear value was obtained for tool 4 at the highest spindle speed of the lathe (n = 250 rpm) which also determines the highest cutting speeds. In this case, the values for maximum and average wear exceed the permissible values. In this case, the lathe tool cannot be resharpened, so it has exceeded its service life.

Table 2. Experimental determinations of wear values on the seating face of cutting tools

No. crt.	Measured values of wear and tear [mm]	Maximum wear [mm]		Medium wear [mm]	
		Admissible value	VB_{BMAX}	VB_B	Admissible value
Tool 1	0,15; 0,17; 0,14; 0,13; 0,17; 0,18; 0,20; 0,25; 0,23; 0,21; 0,19; 0,16; 0,12; 0,11; 0,14; 0,16; 0,11; 0,13; 0,15; 0,15; 0,14; 0,15; 0,15; 0,19; 0,18; 0,17; 0,18; 0,15	0,6	0,25	0,1628	0,3
Tool 2	0,17; 0,25; 0,26; 0,18; 0,15; 0,13; 0,12; 0,16, 0,17; 0,18; 0,25; 0,35; 0,33; 0,32; 0,28; 0,22; 0,13; 0,12; 0,11; 0,12; 0,11; 0,12; 0,10; 0,11		0,35	0,1841	
Tool 3	0,33; 0,33; 0,30; 0,12; 0,11; 0,13; 0,12; 0,12; 0,12; 0,26, 0,27; 0,25; 0,30; 0,50; 0,55; 0,57; 0,59; 0,57; 0,55; 0,54; 0,26; 0,15; 0,16; 0,15; 0,13		0,59	0,2992	
Tool 4	0,49; 0,47, 0,45; 0,43; 0,40; 0,39; 0,40; 0,51; 0,53; 0,55; 0,61; 0,63; 0,65; 0,63; 0,61; 0,58; 0,50; 0,33; 0,40; 0,35; 0,25; 0,20; 0,23; 0,25; 0,27		0,65	0,4444	

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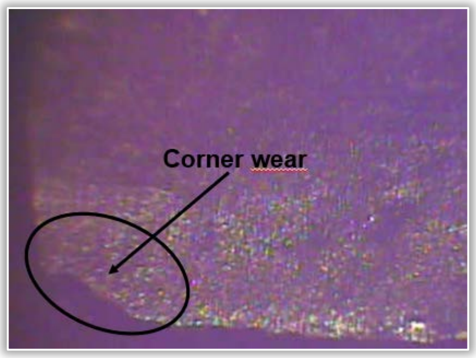
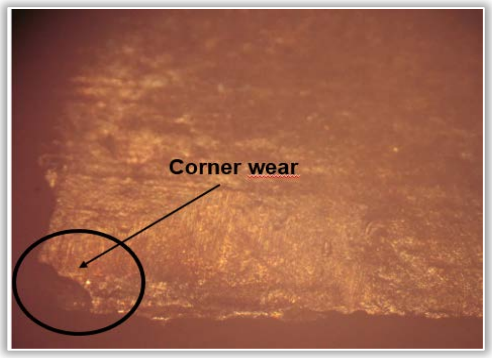
Flank wear was present for all the cutting speeds analyzed, even at low speeds, and increases as the speed increases.

In the case of experiments 3 and 4, the appearance of corner wear is observed, figure 6.



n = 125 rot/min (Tool 3)



n = 250 rot/min (Tool 4)

Figure 6. Corner wear

The occurrence of these wears is explained by the fact that, for these cutting speeds, the flank wear has increased, this being generated by the erosion of small fragments of the cutting tool, due to the adhesion of the material and its subsequent breakage, which led to the chipping of the cutting tool tip. Similar conclusions were reached in the paper [10]. Corner wear of the tool can be considered as part of flank wear because there is no distinct boundary between corner wear and flank wear. Corner wear is considered a separate type of wear due to its importance for machining accuracy. This is explained by the fact that the corner wear shortens the length of the cutting surface by gradually increasing the size of the machined surface and introduces significant dimensional errors in the machining, [10].

Evaluation of the thermal regime in the cutting area

During the experiments, the temperature in the cutting area was also monitored. Developing an adequate model for determining the temperature in the cutting area is a very difficult task due to the large number of interdependent parameters affecting the performance of the process: cutting speed, feed, cutting depth, cutting tool wear, physical and chemical characteristics of the blanks, type of tool coating, [16]. For this reason, experimental investigations were preferred. For this purpose, a thermal imaging camera was used, which allows the temperature to be measured in the temperature range: –35°C – 900°C. The device has a temperature resolution of 0.1°C and an IR accuracy of ± 0.75°C. Figure 7 shows the area where the temperature was analyzed in the study.

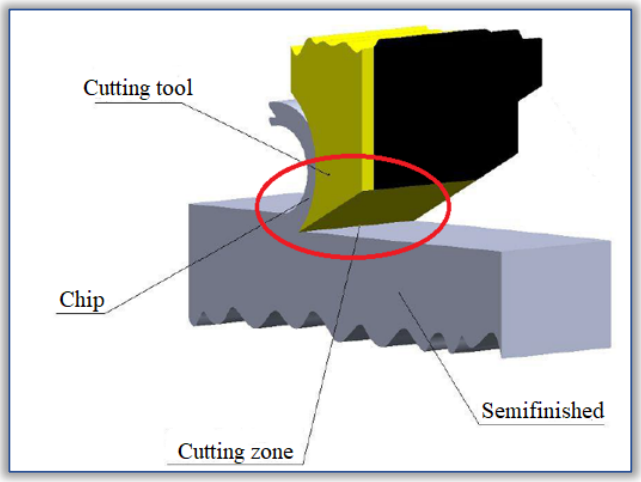


Figure 7. Thermal field monitoring area during experiments

Figure 8 shows the temperature values in the cutting area at the end of the turning of 40Cr10 steel with high–speed steel tool with P30 plate for the cutting regime parameters shown in Table 1. The graph presents in Figure 9 shows the temperature variation in the cutting area as a function of the cutting speed.

Analyzing the graph present in Figure 9, it can be seen that the temperature in the cutting area increases with the increase of the cutting speed. The correlations obtained are presented both in graphical and analytical form, being representative from the point of view of the values obtained for the correlation coefficient (R). The graph shows an

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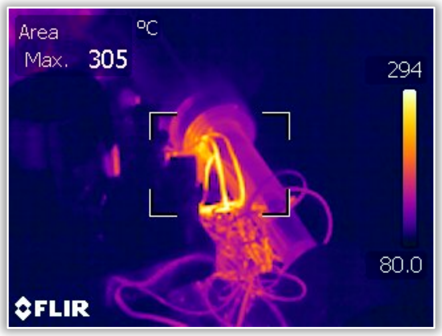
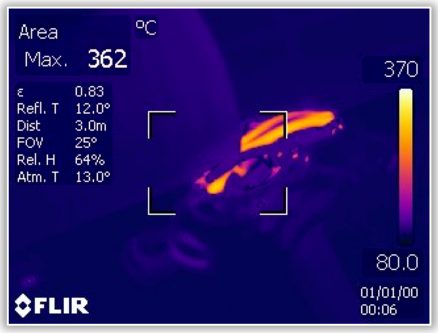
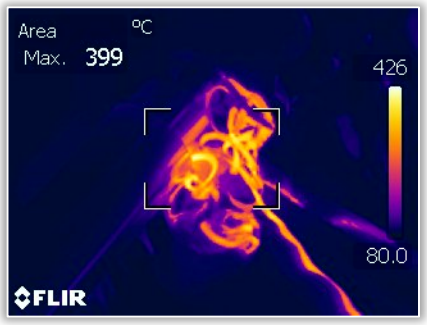
exponential increase in temperature with cutting speed, and the correlation coefficient R^2 = 0.9944 shows a good approximation of the experimental data.



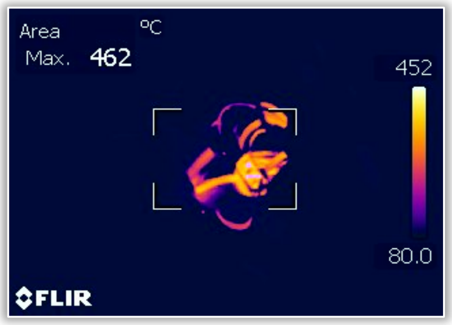
V=4.948 m/min



V=8.704 m/min



V=14.533 m/min



V= 23.648 m/min

Figure 8. Temperature values in the cutting area at the end of turning four–speed roughing machine

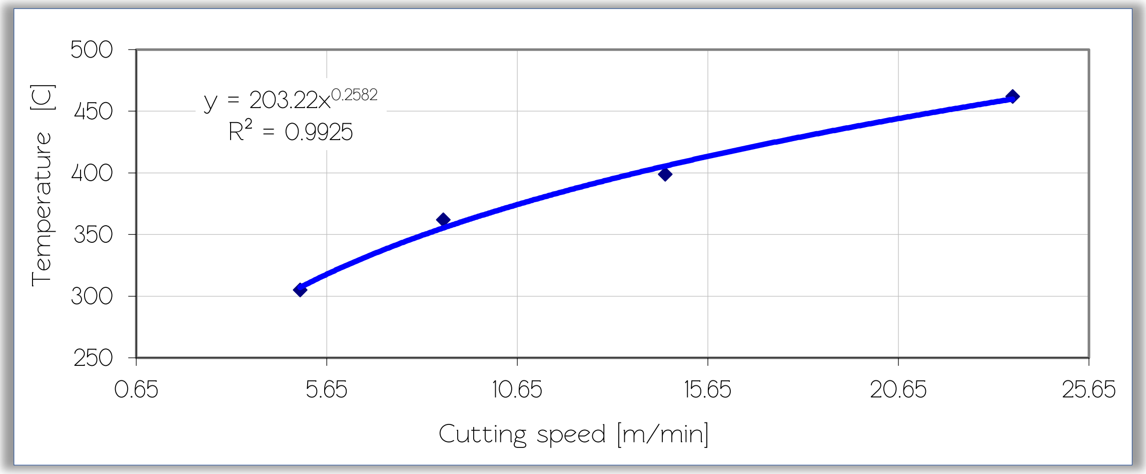


Figure 9. Temperature variation in the cutting area depending on the cutting speed

In the case of turning with the highest cutting speed (Tool 4), the increase in temperature in the cutting area caused an increase in temperature on the surface of the tool. This caused flank wear to occur that was greater than the admissible value. This led to a reduction in the service life of the tool.

During the machining processes, heat develops along the tool–chip and tool–workpiece interface, generated as a result of the plastic deformation of the metal and tribological processes that take place in the cutting area, [14]. This leads to an increase in the temperature of the workpiece, which can lead to dimensional inaccuracies, damage to the machined surface and deformation of the cutting edge. So, it is necessary to control the temperature in the cutting area.

4. CONCLUSIONS

The conclusions at the end of the paper are:

— increasing the cutting speed leads to a rapid increase in temperature in the cutting area;

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- flank wear was present across the entire range of cutting speeds analyzed, even at low values;
- flank wear is a consequence of thermo–mechanical effects, generated by high pressures and temperatures in the cutting area;
- the increase in temperature in the cutting zone determines the development of wear mechanisms that lead to a reduction in the life of the cutting tool;
- the end of the life of cutting tool in the experiment performed with the highest cutting speed was determined by a maximum flank wear (VB_{Bmax}) of 0.65 mm;
- high temperature values in the cutting area lead to a decrease in the strength of the cutting tool and generate wear on the cutting edge;
- the wear of the cutting tool is a real–time evolution process, and the temperature fields in the work piece–cutting tool–chip contact area are continuously changing;
- the thermal regime in the cutting zone determines the wear of the cutting tool, so for efficient cutting, as little heat as possible must be generated and removed from the cutting zone.

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