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EFFECTS OF CUTTING PARAMETERS ON THE FLANK WEAR OF CUTTING TOOLS WITH A CUTTING EDGE

BY

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Abstract. During a machining operation, the main edge of the cutting tool performs most of the cutting, being susceptible to the following types of wear: corner wear, flank wear, and notch wear. The wear is one of the greatest interests because it is the most widely used criterion for determining cutting tool durability. The objective of this paper is to analyze, from an experimental perspective, the effects of cutting parameters on the flank wear of cutting tools with one cutting edge. Thus, three sets of experiments will be performed, each set varying one parameter of the cutting process, while the other two have constant values. In each experiment, the flank wear, thermal load in the cutting zone, and the resulting chips will be determined. The results obtained showed that the wear of the tools is a consequence of thermomechanical effects in the cutting zone.

Keywords: external turning, cutting tool, flank wear, thermal stress, chip.

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1. Introduction

In the current context of cutting technologies, increasing the performance and reliability of tools is a fundamental priority in optimizing manufacturing processes.

One of the critical aspects that directly influences the quality of the finished piece, its accuracy, and production costs is wear (Trent, 1983). One of the most common forms of tool degradation is flank wear, which is characterized by the progressive loss of material from the active surface of the tool. This form of wear affects the quality of the machined surface and can lead to premature tool failure (Merchant, 1945). Cutting parameters play an important role in the evolution of flank wear, both thermally and mechanically. An improper choice of these parameters can lead to increased temperature and excessive stress in the working zone. Over time, these lead to a shortened tool life. Therefore, investigating the relationship between these factors and the wear behavior of single-edged cutting tools is essential to establish effective strategies for increasing tool durability and process productivity (Patric de Vos, 2016). Tool flank wear results in increased cutting forces, which intensifies the thermal regime in the work area. This leads to a change in the profile of the straight edge of the tool with respect to the successive movement of the piece, with negative effects on dimensional accuracy (Siddhpura and Paurobally, 2013). When the tool's service life has been reached, it fails due to excessive mechanical and thermal stresses in the work area, which is why it must be replaced (Bloul *et al.*, 2024). Interruption of processing to replace or sharpen the cutting edge will be performed at the stage when the admissible wear is reached (Devillez *et al.*, 2004). To accurately estimate the moment when acceptable wear is about to be reached, monitoring the evolution of tool wear remains a constant area of interest.

The paper aims to analyze, from an experimental perspective, the influence of cutting parameters on the wear of cutting tools with a cutting edge. Thus, three sets of experiments will be performed, each set varying one parameter of the cutting regime, while the other two have constant values. In each experiment, flank wear, the thermal regime in the working area, and the resulting chips will be analyzed.

2. Problem description and experimental details

According to the ANSI/ASME B94.55M-1985 (R2003) standard, the wear of cutting tools on the flank face can be divided into three categories: corner wear (C), flank wear (B), and notch wear (N) (Salvatore *et al.*, 2013).

Fig. 1 shows how to divide the cutting surface into three zones. Corner wear occurs in the C zone, towards the seating face, and the length of the face used for machining gradually decreases (Bin, 2012). Flank wear occurs in the B zone, as a result of friction in the process, and results in dimensional changes in the machined parts (Bloul *et al*., 2024). Notch wear occurs in the N zone and is caused by fatigue wear and/or an existing inclusion in the workpiece material (Siddhpura and Paurobally, 2013).

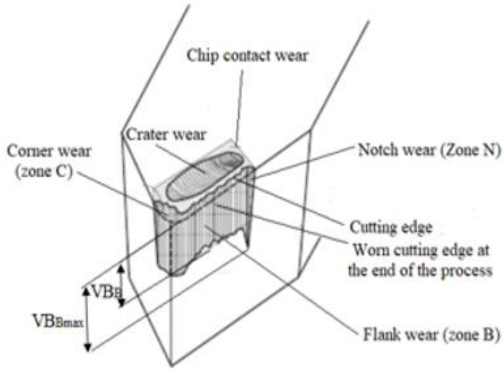

Fig. 1 – Presentation of the three characteristic areas.

One of the factors that determines this type of wear is the oxidation of the tool material generated by oxygen in the air that has access to this surface, as a result of the high thermal regime in the work area. Of the previously mentioned variants, the wear of the flank is of the greatest interest because it occurs on any type of cutting edge and represents the criterion most commonly used to determine the durability of the cutting tool (Qehaja *et al*., 2017). The recommended values for permissible tool wear depend on the material from which they are made (Salvatore *et al*., 2013).

During the cutting process, the workpiece material deforms to the point of yielding. In this context, a large amount of heat is generated, which is reflected in the high temperature in the cutting zone. These temperatures are responsible for the rapid deterioration of tools. Fig. 2 shows the thermal field that appears in the cutting, comprising the workpiece, chip, and cutting tool (Patrick de Vos, 2016).

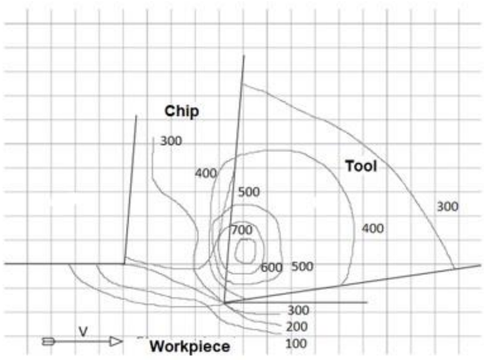

Fig. 2 – Thermal field in the cutting zone.

On the other hand, a particularly important role in the machining is played by the formation and fragmentation of chips. Knowledge of chip morphology contributes to increasing the machinability and productivity of the process (Daicu and Oancea, 2022).

The experiments were conducted on a lathe of type SCU 500 x 2000 mm. Each turningoperation was performed on a workpiece made of AISI 5140, a medium-hard alloy steel resistant to fatigue and wear under dynamic conditions. The choice of this material was due to its relevance in the automotive industry: crankshafts, camshafts, pinions, axles, transmission shafts, components of the steering system, and suspension. For each experiment, a workpiece with a diameter of 100 mm and a length of 400 mm was used. In the experiments, HSS tools are used, with 20x20mm dimensions and P30 insert, produced by Hoffman Group and the process is performed without the use of coolants. All new tools used for each experiment have the same initial geometric characteristics and the same tool adjustment parameters The processing time was 10 min.

The experimental strategy consists of performing three orthogonal turns with the parameters presented in Table 1. In this table, the speed was calculated with Eq. (1):

$$v = \frac{\pi \cdot d \cdot n}{1000} \tag{1}$$

where: d is the diameter of the work-piece, [mm], and n – the spindle speed, [rpm].

Table 1

Cutting parameters

No.	Spindle speed n [rpm]	Cutting speed v [m/min]	Depth of cut a_p [mm]	Feed f [mm/rot]
Exp. 1	63	19.79	2	0.075
Exp. 2	125	39.26		
Exp. 3	250	78.53		

The offline method for evaluating wear on the flank face was used, which involves measuring wear outside the process under laboratory conditions. To determine wear according to the ANSI/ASME Tool Life Testing Standard, a microscope with an optical interface, type A- KRÜSS Optronic, was used. This microscope has a measurement range of 0–50 mm, with a maximum allowed error of 3 μm and USB interface (Cabibbo *et al.*, 2017). At the end of each experiment, the temperature in the cutting area was measured using a FLIR A35 thermal camera, and the resulting chips were photographed to study their morphology.

To determine wear in B zone, the methodology presented in the works by (Daicu and Oanea, 2022) and (Dițu, 2021), which proposes an incremental measurement and the drawing the wear profile based on the measurement results, was adopted. Thus, the following steps were taken:

- microscopic visualisation of wear at the end of the process;
- determination of the reference line of the initial profile;
- determining the length of the worn zone (L_u), excluding the area corresponding to the tip of the tool;
- calculating the length of the worn surface with Eq. (2):

$$L_{wear} = \frac{L_u}{p} + 1 \quad (2)$$

where: p = 0.1 mm represents the measuring step;

- calculation of the number of wear measurement points by dividing the worn surface into parallel sections with a step of 0.1 mm;
- measuring the depth of wear at each point;
- determination of maximum wear VB_{Bmax};
- comparing the values obtained with the admissible ones.

Figs. 3, 4, and 5 show the characteristics of flank wear in the turning operations performed.

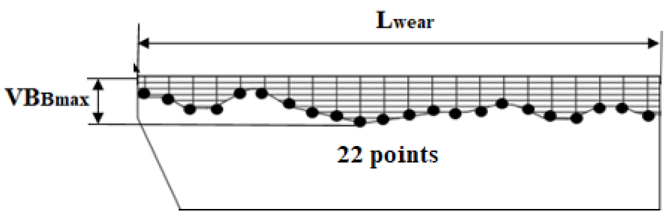

Fig. 3 – Determination of flank wear in Experiment 1, turning at 63 rpm, with a cutting speed of 19.79 m/min.

Applying the wear determination methodology to the flank face of the three worn cutting edges led to the results shown in Table 2. Additionally, this table highlights the temperatures in the cutting zone at the end of each experiment.

Table 2

Flank wear and cutting zone temperatures at the end of the experiments

No.	Length of straight worn edge L_u [mm]	Number of measurement points L_{wear}	Maximum wear VB_{BMAX} [mm]	Admissible wear VB_{Bmax} [mm]	Temperature at the end of processing T [ºC]
Exp. 1	2.1	22	0.28	0.6	321
Exp. 2	2.3	24	0.45		498
Exp. 3	2.4	25	0.63		562

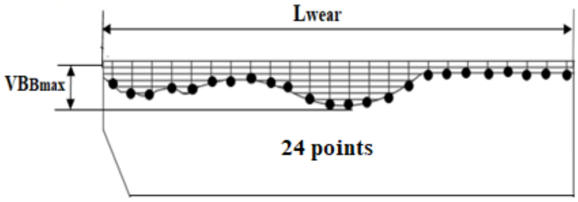

Fig. 4 – Determination of flank wear in Experiment 2, turning at 125rpm, with a cutting speed of 39.26 m/min.

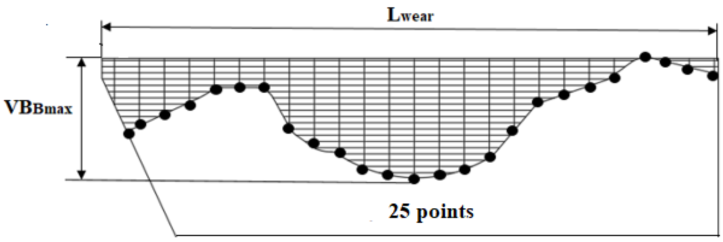

Fig. 5 – Determination of flank wear in Experiment 3, turning at 250 rpm, with a cutting speed of 78.53 m/min.

Flank wear was present for all cutting speeds analysed, even at low speeds, and increases as the cutting speed increases. Table 2 shows that the maximum flank wear values from Experiment 1 and 2 are lower than the admissible value. The highest wear value was obtained in Experiment 3. In this experiment, characterised by the highest cutting speed, the value obtained for maximum wear exceeds the admissible value. In this case, the tool cannot be resharpened, so it has exceeded its service life.

Fig. 6 shows the graph of the variation of maximum flank wear as a function of cutting speed.

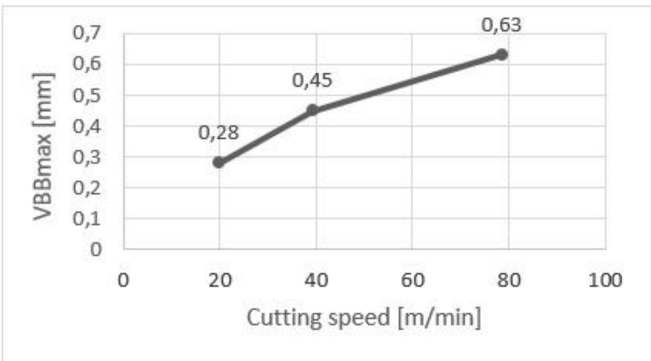

Fig. 6 – Evolution of flank wear depending on cutting speed.

Fig. 6 shows an increase in flank wear with speed.

Regarding the shape of the resulting chips, they are presented in Table 3.

Table 3

Chip shape at the end of the experiments

Turning 1	Turning 2	Turning 3
		

In Experiment 1, the chips are continuous, of different lengths, and are more easily fragmented.

In Experiment 2, the chips are short, segmented, showing return colours, and were easily evacuated from the work area. The speed of 125 rpm is double that of the previous one, so the cutting speed has also increased significantly. This is due to the presence of a greater amount of heat in the cutting area, allowing the material to deform plastically and shear more easily.

In Experiment 3, the chips are short, segmented, brittle, and easily removable. The chips show recovery colours, due to the high thermal regime in the shear zone of the chip, as can be seen in the results presented in Table 2. This thermal regime is generated by the high cutting speed, which makes the processed material more plastic, and the chip breaks more easily.

Increasing the spindle speed and, implicitly, the cutting speed leads to an increase in the thermal regime in the working area. This is due to the fact that the mechanical energy converted into heat is directly proportional to the cutting speed. Thus, friction and plastic deformation occur more rapidly and intensely, resulting in a greater amount of heat being developed in a relatively short time. Under these conditions, the greatest amount of heat accumulates in the cutting tool and chip.

To study the influence of feed on flank wear, three different were considered. The cutting speed is a moderate one for machining AISI 5140 material with HSS tools. The parameters used in the experiments, along with the temperatures at the end of them, are presented in Table 4. The determination of flank wear was carried out according to the methodology presented previously. In the experiments, the spindle speed was 125 rpm and the cutting depth was 2 mm.

At low feed rates (Experiment 4), friction is low and wear is slow.

At medium feed rates (Experiment 5), wear becomes visible, and temperatures increase.

Table 4
Cutting parameters, flank wear, and temperatures at the end of the experiments

No.	Feed f [mm/rot]	Flank wear VB_{BMax} [mm]	Admissible wear V_{Bmax} [mm]	Temperature at the end of processing T [^{0}C]
Exp. 4	0.05	0.25		318
Exp. 5	0.075	0.39	0.6	415
Exp. 6	0.1	0.60		542

At high feeds, as in Experiment 6, friction and cutting temperature will lead to rapid tool wear, and the material is cut aggressively.

When the feed rate increased, it was observed that the wear was significant and reached the maximum allowable value.

Fig. 7 shows the dependence of the wear of the feed.

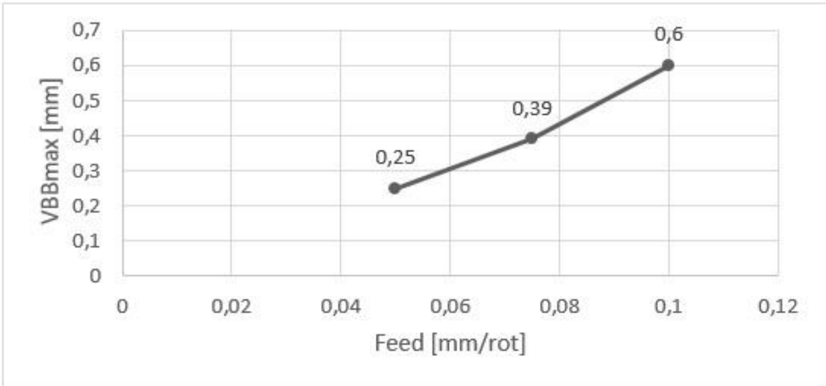

Fig. 7 – Evolution of flank wear depending on feed.

Regarding the shape of the resulting chips, they are presented in Table 5.

Table 5
Chip shape results at the end of the experiments

Turning 4	Turning 5	Turning 6
		

In Experiment 4, the chips are thin, uniform, continuous, and long. Their fragmentation is reduced. Low feed is most effective for good control of the cutting process. Chip fragmentation is minimal, and the machining process is stable but slower.

In Experiment 5, performed with a medium feed rate, the chips are thicker, bulkier, and shorter, and fragmentation begins to be visible. Because the feed is higher, the cutting force is also higher, and a larger volume of material is removed. This slightly increases the thermal regime in the cutting area. The fragmentation of chips into smaller segments occurs as a result of the increased stresses generated by the higher feed rate.

In Experiment 6, the chips are thick, break quickly into small fragments, and are removed from the work area in a rapid stream. Although the cutting speed is moderate, high feeds lead to increased cutting forces and temperature, generating an additional thermo-mechanical regime on the tool and the workpiece material.

Increasing the feed rate causes faster flank wear, but not as much as increasing the speed. The thermal regime increases with the feed rate, with negative influences on the tool durability.

To study the influence of cutting depth on flank wear, three different values were considered. The parameters used in the, along with the temperatures at the end of them, are presented in Table 6. The determination of flank wear was carried out according to the methodology presented previously. In the experiments, the spindle speed was 125 rpm and the feed was 0.075 mm/rev.

Table 6

Cutting parameters, flank wear, and temperatures at the end of the experiments

No.	Depth of cut a_p[mm]	Flank wear V_{BMax} [mm]	Admissible wear V_{Bmax} [mm]	Temperature T [^{0}C]
Exp.7	1	0.25	0.6	112
Exp.8	2	0.39		256
Exp.9	3.5	0.60		311

Increasing the depth of the cut moderately increases the wear of the flanks. This is due to the low cutting speed and relatively low feed. Thus, the contact surface between the tool and the workpiece increases, and friction intensifies the wear of the cutting tool. In this situation, the increase in wear is controllable because the cutting speed is low. Fig. 8 shows the graph of the variation of maximum flank wear as a function of cutting depth.

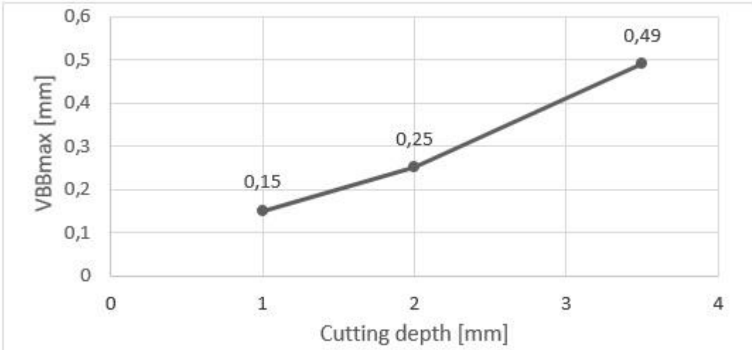

Fig. 8 – Evolution of flank wear depending on cutting depth.

The shape of the chips resulting from these experiments is presented in Table 7.

Table 7

Chip shape at the end of the experiments

Turning 7	Turning 8	Turning 9
		

In Experiment 7, the chips are thin, in the form of a tight, smooth spiral, silver-grey in color. The thermal regime in the cutting zone is relatively low.

In Experiment 8, the chips become wider and thicker, dark grey, slightly wavy, with sharp edges.

In Experiment 9, the chips are thick, short, and stiff, broken irregularly. The chip colour is brown to orange due to oxidation and increased temperature.

A large depth favours chip fragmentation as a result of the high stress on the material and the tendency to form segmented chips. Increasing the depth of cut causes the chip cross-section to increase. Thus, more energy is dissipated, which causes the temperature to increase. However, the temperature has values lower than those in the previously analyzed cases. Increasing the cutting depth causes moderate wear and a relatively small increase in the thermal regime within the working area.

3. Conclusions

This paper experimentally investigates how cutting parameters affect flank wear in single-edged turning tools. By varying one cutting parameter per test while keeping others constant, it analyzes tool wear, thermal conditions, and chip formation. The results obtained show that cutting speed has the greatest influence on temperature and, implicitly, on thermal wear on the flank. Feed leads to flank wear as a result of cutting forces that generate mechanical wear. Regarding the cutting depth, this influences the flank wear depending on the active surface involved in process. Depth of cut mainly influences chip size and moderate mechanical and thermal wear.

In conclusion, flank wear of cutting tools with one cutting edge is a consequence of thermo-mechanical effects in the cutting zone.

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EFECTELE PARAMETRILOR DE AŞCHIERE ASUPRA UZURII PE FLANC A SCULELOR AŞCHIETOARE CU O MUCHIE DE TĂIERE

(Rezumat)

Strunjirea se execută cu scule aşchietoare cu o muchie de tăiere numite cuţite de strunjire. În timpul unei operaţii de prelucrare, muchia principală a sculei aşchietoare execută cea mai mare parte a aşchierii, fiind susceptibilă la următoarele tipuri de uzuri: uzură la colţ, uzură pe flanc şi crestătură. Uzura pe flanc prezintă cea mai mare importanţă, deoarece este criteriul cel mai utilizat pentru determinarea durabilităţii sculei aşchietoare. Obiectivul acestei lucrări este de a analiza, dintr-o perspectivă experimentală, efectele parametrilor regimului de aşchiere asupra uzurii pe flanc a sculelor aşchietoare cu o muchie de tăiere. Astfel, se vor efectua trei seturi de experimente, în fiecare set variind un parametru al regimului de aşchiere, în timp ce ceilalţi doi au valori constante. În fiecare experiment, la sfârşitul fiecărui proces de prelucrare se va determina uzura pe flanc, regimul termic în zona de aşchiere şi aşchiile rezultate. Concluziile obţinute au arătat că uzura sculelor este o consecinţă a efectelor termomecanice din zona de aşchiere.