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Study of the influence of cutting parameters on tool wear and the state of the machined surface

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Abstract

This work presents a study of wear on the clearance face of turning tools. This study will contribute to the development of improved machining precision and efficiency while extending tool life and also ensuring the surface quality produced, despite wear and edge deposition phenomena. A tool flank wear model is developed as a function of the cutting conditions, including the cutting speed, depth of cut, feed rate, and machining time. Factors influencing tool clearance face wear are determined through experimental testing. We also investigate the edge phenomenon reported on the tool cutting face by plotting a curve of the edge variation versus the machining time. Tool wear and built-up edge phenomena both affect the quality of the surface finish produced. Additionally, the edge phenomenon degrades the geometric quality of the tool and generates wear on the tool clearance face. Therefore, models are developed to aid in selection of appropriate cutting conditions that ensure the expected surface finish is realized while also providing control over tool wear. Overall, this method combines experimental and theoretical approaches to study and control turning tool wear with the aim of improving both machining quality and efficiency.

Keywords

Flank wear, built-up edge, cutting, turning, modelling, tool clearance face

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Introduction

Wear involves a complex set of phenomena that are difficult to interpret and causes an emission of debris with an associated loss of mass, dimension, and shape that is accompanied by physical and chemical transformations of the surfaces affected.¹ A large part of wear involves chemical reactions; chemically inert surface layers can sometimes prove to be more resistant to friction than hard layers, particularly in the presence of aggressive media. Wear is generally combated because of its negative effects but it also has favourable aspects for use in applications such as sharpening of tools or finishing of surfaces by grinding.²

In the case of machining, these wear phenomena are essentially dependent on the cutting temperature. Two large groups of parameters can be observed during the

cutting process: the first is represented by the properties of the machined material and the second comprises the cutting conditions (i.e., the cutting speed, feed, depth of cut, and lubrication properties).³

Cutting tool wear occurs as a result of the very severe stresses that act on the cutting and clearance faces. These stresses are primarily mechanical in nature

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(e.g., permanent or cyclic stresses, the action of friction), which requires the cutting tool to have the qualities of hardness and tenacity. The intensity of these applied stresses is heightened by thermal effects, which accelerate the wear of the tool material and lead to its degradation. Moreover, these effects can produce physico-chemical reactions that mainly occur at the cutting face level (the tool-chip interface) and further aggravate the tool wear.⁴ Wear of cutting tools affects both the quality of the parts produced and the cost of the machining process. When the wear reaches a certain critical value, the cutting forces, the process temperature and the vibrations all increase significantly and cause the stability of the cut to deteriorate. The machining operation must then be interrupted to replace the worn tool.⁵ This tool replacement time and the low machining quality generated on the part increase costs and reduce productivity considerably.⁶ At present, empirical approaches are used in industry to estimate tool life, but the empirical formulas obtained (wear laws) are based on numerous experimental tests that are often costly to perform and time-consuming. It is therefore necessary to develop a theoretical and experimental approach that can estimate the wear and the lifetimes of cutting tools while controlling the number of experimental tests required. The factors that influence wear are detailed in the diagram in Figure 1.

Principle of tool wear

Built-up edge (BUE) is not a tool wear phenomenon (Figure 2). However, it has the same impact on machining as tool wear, i.e., a reduction in the cutting ability of the edge. Part of the material from the workpiece is deposited on the cutting edge, where it coats the cutting tool material and alters the geometry of its cutting edge.⁷ The hardness of the cutting edge then becomes

that of the workpiece material. This reduces the tool's cutting efficiency.

Therefore, the occurrence of the BUE causes dimensional inaccuracy and produces a poor surface finish on the machined part.

The BUE phenomenon occurs when the cutting speed is too low. This can occur with parts made from any material, most commonly with aluminium but also with steels, during turning and milling operations.⁸ The material of the part at the cutting edge reaches a plastic (semi-solid) stage and then solidifies on the cutting edge. The strategy used to avoid the occurrence of BUE is to increase the cutting speed, causing the temperature at the cutting edge to increase to the point where the cut metal only solidifies after it leaves the cutting edge.⁹ However, increasing the cutting speed in this manner can also generate an increase in wear.

Representation of built-up edge and flank wear

Using the data presented in Figure 3, the limits of both the wear zone and the added edge can be traced. The dashed line represents the main cutting edge of the tool and all the lines that lie above this dashed line represent the added edge as a function of time.⁶ The BUE can then be evaluated by calculating the area between the two curves, as follows:

$$S_{BUE} = \int_{-0.01}^{1.972} (Y(X) - 0.015) dY \quad (1)$$

where $Y(X)$ is the upper curve of the BUE.

Model of main clearance face wear

The classical empirical wear law in draft form is given by equation (2).¹⁰

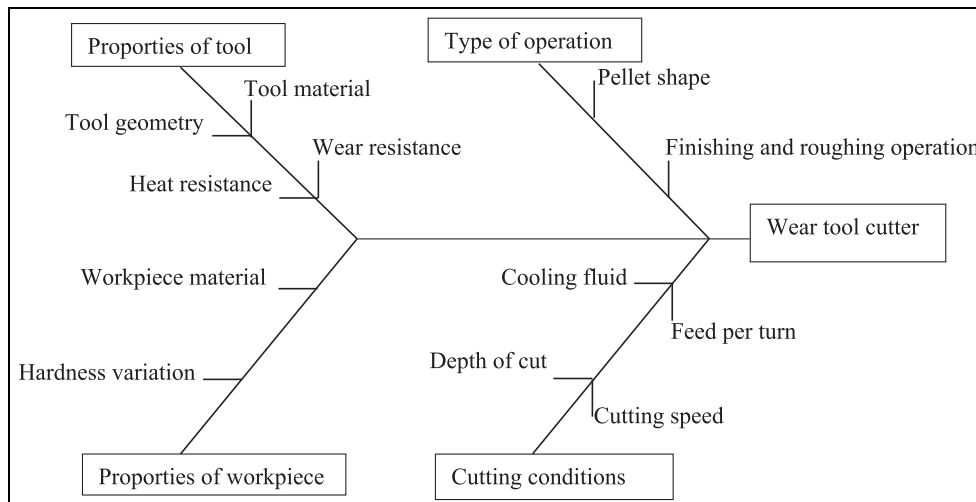


Figure 1. Diagram illustrating the parameters that affect tool wear.

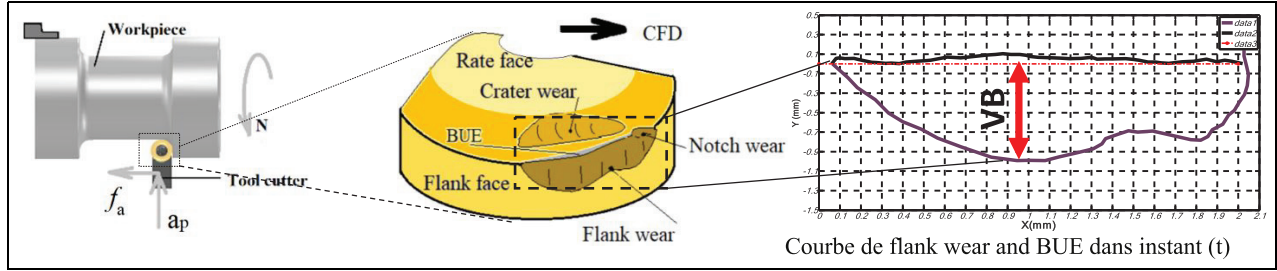


Figure 2. Stages of wear formation and development of the built-up edge on the tool.

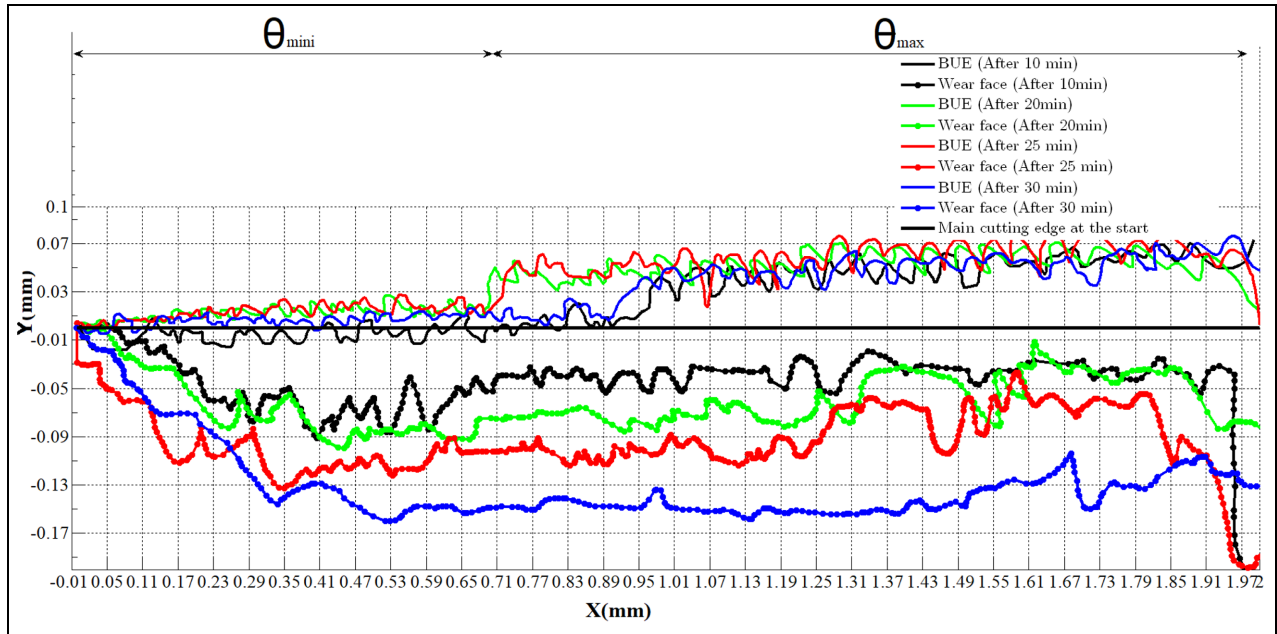


Figure 3. Curves of the wear edge and clearance face limits (cutting speed $V_c = 52.5$ m/min and the feed per turn $f_a = 0.2$ mm/turn).

$$VB(t) = kV_c^{a_1} f_a^{a_2} a_p^{a_3} a_e^{a_4} t^{a_5} \quad (2)$$

where $VB(t)$ is the flank wear, k is a constant, V_c is the cutting speed, f_a is the feed per turn, a_p is the depth of cut, a_e is the tool engagement and t is the machining time. The parameters k , a_1 , a_2 , a_3 , a_4 and a_5 are identified through experimentation and are dependent on both the tool and the material used for the part.

This nonlinear equation can be transformed into a linear equation using the log function. We then obtain equation (3).

$$\begin{aligned} \log VB(t) = & \log k + a_1 \log V_c + a_2 \log f_a + a_3 \log a_p \\ & + a_4 \log a_e + a_5 \log t \end{aligned} \quad (3)$$

Equation (3) can be represented as a straight line as follows:

$$Y = aX + b \quad (4)$$

Identification of the parameters for equation (4) from the test results is conducted by applying the least squares method.

The matrix for this method is defined as follows:

$$\begin{aligned} \begin{pmatrix} \log VB(t_1) \\ \log VB(t_2) \\ \log VB(t_3) \\ \dots \\ \log VB(t_n) \end{pmatrix} = \begin{pmatrix} a_1 \\ a_2 \\ a_3 \\ \dots \\ a_4 \\ a_5 \end{pmatrix} * \begin{pmatrix} 1 & \log V_{c1} & \log f_{a1} & \log a_{p1} & \log a_{e1} & \log t_1 \\ 1 & \log V_{c2} & \log f_{a2} & \log a_{p2} & \log a_{e2} & \log t_2 \\ 1 & \log V_{c3} & \log f_{a3} & \log a_{p3} & \log a_{e3} & \log t_3 \\ \dots & \dots & \dots & \dots & \dots & \dots \\ 1 & \log V_{cn} & \log f_{an} & \log a_{pn} & \log a_{en} & \log t_n \end{pmatrix} \end{aligned} \quad (5)$$

This matrix then follows the form of equation (3) and is represented as a line in the following form:

$$Y_n = a_{j(j=1,2,3,4,5)} X_n + b_n \quad (6)$$

such that $n = 1, 2, \dots$, represents the total test numbers.

The least squares method is then used to evaluate the parameters. A^* is the optimal value of A that adjusts

the model to fit the data most accurately and is evaluated using the least squares method, along with a tropic equation, and optimal values are found for the following parameters: k , a_1 , a_2 , a_3 , a_4 , and a_5 .

Experimental Method

Identification of the parameters requires implementation of the experimental tests that are detailed in the following paragraphs.

Tool and workpiece characteristics

The machined piece is composed of treated Inconel 718 with a hardness of 45 HRC. The diameter of the piece is 45 mm and its length is 80 mm (Figure 4a). The cutting tool is a round carbide insert with a nose radius of 4 mm and a height of 4 mm (Figure 4b). When this tool is mounted in the tool holder, the clearance angle is 6° . Flood cooling conditions are applied using a water-based emulsion coolant with oil content.

This study considers the turning operation required to form a deep groove with a depth of 4 mm and length of 20 mm at three cutting speeds, $\epsilon \{35; 52.5; 70\}$ m/min, at three forward speeds $\epsilon \{0.1; 0.2; 0.3\}$ mm/turn and with a depth of cut a_p of between 0.5 and 8 mm (see Table 1).

Table 1. Parameters taken from the experimental section.

t (min)	VB (mm)	V_c ($\frac{m}{min}$)	f_d ($\frac{mm}{t}$)	a_p (mm)	a_e (mm)
4.99	0.091	35	0.1	0.5	0.5
10	0.123	35	0.1	1	0.5
54	0.292	35	0.1	5.5	3
2.49	0.09	35	0.2	0.5	0.5
39.94	0.292	35	0.2	8	6
3.01	0.071	52.5	0.1	0.5	0.5
18.83	0.294	52.5	0.1	5.5	3
1.50	0.075	52.5	0.2	0.5	0.5
15.09	0.31	52.5	0.2	5	4
0.86	0.067	52.5	0.35	0.5	0.5
2.26	0.066	70	0.1	0.5	0.5
1.13	0.077	70	0.2	0.5	0.5
0.64	0.066	70	0.35	0.5	0.5

t : machining time; VB : flank wear; V_c : cutting speed; f_d : feed per turn; a_p : depth of cut; a_e : tool engagement.

Calculation of the maximum and minimum angles at the contact position of the tool and the workpiece

Based on the simulations illustrated in Figure 5, the maximum and minimum angles at the contact position of the cutting tool and the machined part in the reference plane can be determined using two cutting parameters, comprising the feed rate and the depth of cut a_p , and the nose radius of the tool r_e (Figure 6).

The minimum angle defines the location of the beginning of the contact between the tool and the

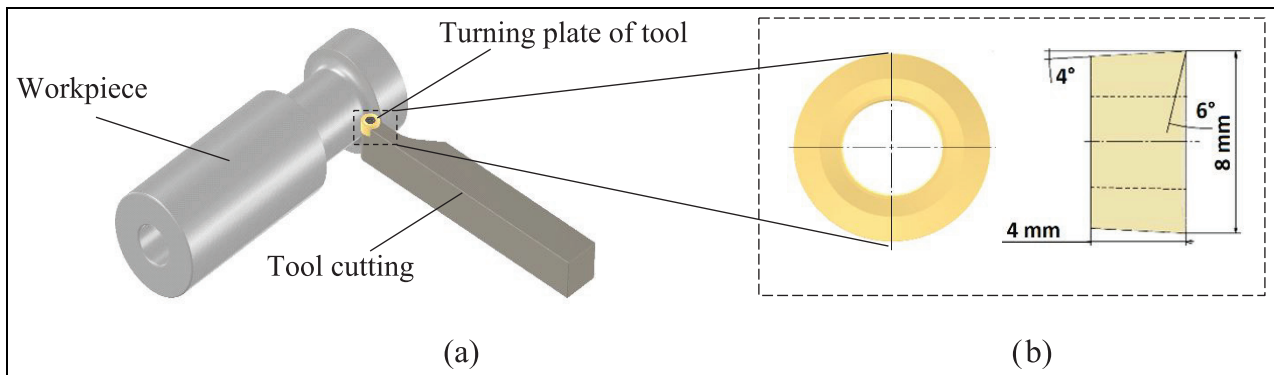


Figure 4. Illustrations of: (a) the machining test and (b) the geometry of the cutting tool used.

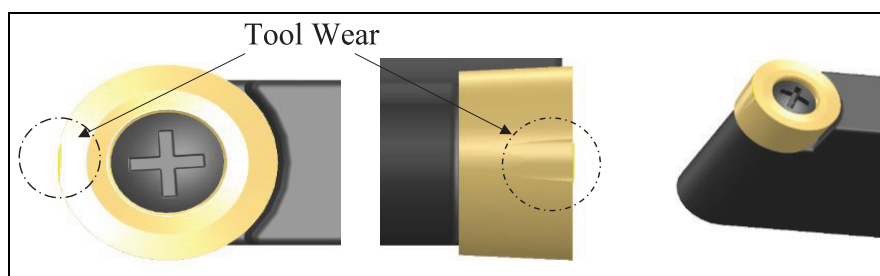


Figure 5. Simulations showing the tool wear after machining.

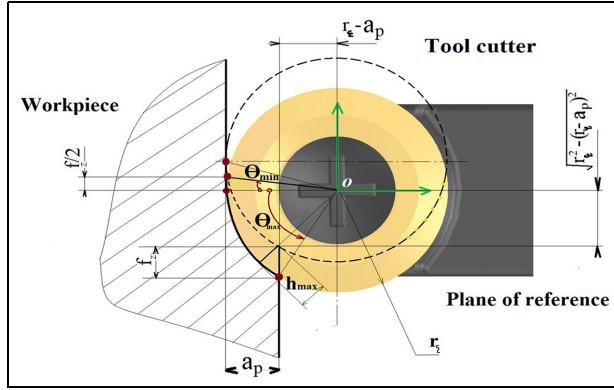


Figure 6. Maximum and minimum angular positions for contact between tool and workpiece.



Figure 7. Tool flank wear: $VB=0.091$ mm, $V_c=35$ m/min, $a_p=0.5$ mm and $t=4.99$ min.

surface to be machined. This angle depends on f_a and r_ϵ , as shown in equation (7).

$$\theta_{min} = \arcsin\left(-\frac{f_a}{2r_\epsilon}\right) \quad (7)$$

The maximum angle defines the position of the end of contact between the tool and the machined surface. This angle depends on p and r_ϵ , as shown in equation (8).

$$\theta_{max} = \arcsin\left(1 - \frac{a_p}{r_\epsilon}\right) \quad (8)$$

Finally, the maximum depth of path h_{max} can be computed, as shown in equation (9).⁸

$$h_{max} = r_\epsilon - \sqrt{(r_\epsilon - a_p)^2 + (\sqrt{r_\epsilon^2 - (r_\epsilon - a_p)^2} - f_a)^2} \quad (9)$$

$$\theta_{rmax} = \arcsin\left(\frac{r_\epsilon - a_p}{r_\epsilon - h_{rmax}}\right) \quad (10)$$

Pictures of tool wear and BUE

After a machining trial was performed on a computer numerical control (CNC) machine that involved turning using a round insert tool, images of the clearance face of the tool were acquired at different times using a 42-pixel camera (see Figures 7, 8, 9, 10, 11, 12, 13, 14 and 15).

The results for the experimental part of the wear are summarized as a function of the parameters VB , V_c , f_a , a_p and a_e in Table 1.

The linear equation system in equation (4) is solved using the least squares method to calculate the unknown factors of the linear system and the results are given in Table 2, as follows:

Tool wear model

Matlab calculation software was used to determine the following unknowns: a_1 , a_2 , a_3 , a_4 and a_5 .

This allows us to give equation (9) in the following form:

$$VB(t) = 0.4897 V_c^{-0.4897} f_a^{-0.2002} a_p^{0.6763} a_e^{0.0013} t^{-0.1579} \quad (11)$$

Results and discussion

Through experimentation, we have identified the tool wear law for a coupled tool/machined part material system.

It should be remembered that the causes of wear and BUE can include:

- A cutting zone temperature that is too low;
- A negative cutting geometry;
- Machining of very sticky materials, including low carbon steel, stainless steels and Inconel 718.

Therefore, we can propose the following suggestions to reduce wear and BUE:

- Increase the cutting speed;
- Use tools that have a more positive rake angle and a sharper cutting edge;
- Increase the coolant supply dramatically.

Conclusion

This article presents the results of a study in which a draft wear law was identified for a turning operation on Inconel 718 samples. An experimental testing approach



Figure 8. Tool flank wear: $VB=0.123$ mm, $V_c=35$ m/min, $a_p=0.5$ mm and $t=10$ min.



Figure 11. Tool flank wear: $VB=0.294$ mm, $V_c=52.5$ m/min, $a_p=5.5$ mm and $t=18.83$ min.



Figure 9. Tool flank wear: $VB=0.292$ mm, $V_c=35$ m/min, $a_p=0.5$ mm and $t=54$ min.

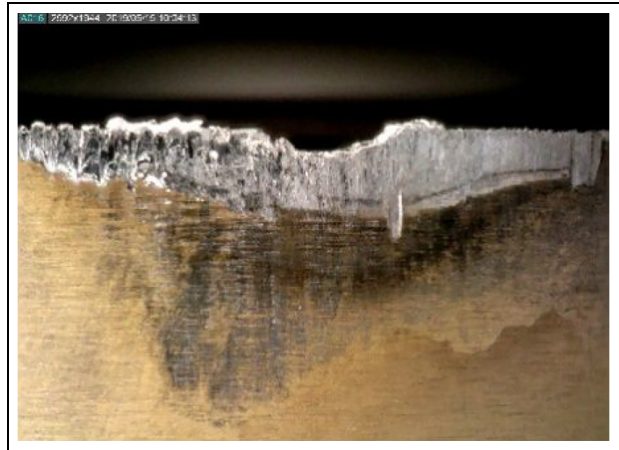


Figure 12. Tool flank wear: $VB=0.31$ mm, $V_c=52.5$ m/min, $a_p=5$ mm and $t=15.09$ min.



Figure 10. Tool flank wear: $VB=0.071$ mm, $V_c=52.5$ m/min, $a_p=0.5$ mm and $t=3.01$ min.



Figure 13. Tool flank wear: $VB=0.066$ mm, $V_c=70$ m/min, $a_p=0.5$ mm and $t=2.26$ min.

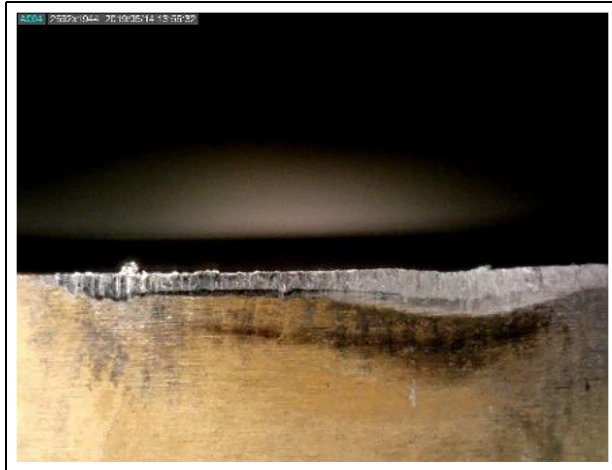


Figure 14. Tool flank wear: $VB=0.077$ mm, $V_c=70$ m/min, $a_p=0.5$ mm and $t = 1.13$ min.

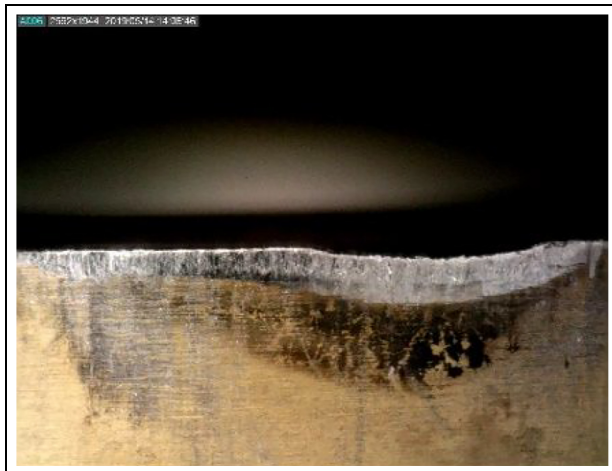


Figure 15. Tool flank wear: $VB=0.066$ mm, $V_c=35$ m/min, $a_p=0.5$ mm and $t= 0.64$ min.

Table 2. Determined values of unknown linear system factors.

k	a_1	a_2	a_3	a_4	a_5
0.4897	-0.4193	-0.2002	0.6763	0.0013	-0.1579

enabled identification of the parameters for the flank wear law. This experimental approach made it possible to model both the tool clearance face wear and the BUE, which varies as a function of time. Analysis of the experimental results made it possible to consider the following:

- The predominant wear phenomenon is abrasive wear. This phenomenon is manifested through the appearance of grooves (striations) on the

flank face of the tool. Abrasive wear occurs as a result of particles being torn from the tool by the hard particles that constitute the machined material. At cutting speeds of 35, 52.5 and 70 m/min, the tool wear manifests through the appearance of a ridged and regular band on the relief surface and through formation of a crater on the attack surface. Over time, we noticed an increase in the wear VB , which leads to the collapse of the nose of the tool.

- Cutting speeds in excess of 70 m/min are not recommended because they lead to rapid tool wear. This causes the tool lifespans to be too short, which is not of industrial interest.
- Wear is one factor to be considered in machining because its evolution damages and degrades the surface condition of the machined parts.
- The determination of the mathematical models of wear and roughness is of significant industrial interest because these models enable determination of the optimal machining conditions and the development of charts for the process. During roughing operations, in which substantial amounts of material are removed from a workpiece to approach its final dimensions, formation of the BUE can indeed play a protective role for the tool. This occurs because the BUE acts as an additional layer on the cutting edge of the tool, which can reduce tool abrasion and extend the tool's lifespan. Furthermore, BUE can help to stabilize the machining process by reducing vibrations and enhancing the tool's thermal stability. However, during finishing operations, where tight tolerances and a high-quality surface finish are required, the presence of the BUE can become problematic.^{11–16} BUE can lead to the occurrence of undesirable marks on the machined surface, thus compromising the quality of the final part. Additionally, during finishing operations, light passes and reduced feeds are often used, and they may not be sufficient to break or remove the BUE effectively.

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References

1. Toubhans B, Fromentin G, Viprey F, et al. Machinability of Inconel 718 during turning: Cutting force model considering tool wear, influence on surface integrity. *J Mater Process Technol* 2020; 285: 116809. DOI: 10.1016/j.jmatprotec.2020.116809.
2. Blouet J. Usure. *Techniques de l'Ingénieur*. 1978; B585: 1–34.
3. Trent EM. Some factors affecting wear on cemented carbide tools. *Proc Inst Mech Eng* 1952; 1: 64–75.
4. Baig RU, Javed S, Khaisar M, et al. Development of an ANN model for prediction of tool wear in turning EN9 and EN24 steel alloy. *Adv Mech Eng* 2021; 13: 1–14. DOI: 10.1177/16878140211026720journals.sagepub.com/home/ade.
5. Binder M, Klocke F and Doebbler B. An advanced numerical approach on tool wear simulation for tool and process design in metal cutting. *Simul Model Pract Theory* 2017; 70: 65–82. DOI: 10.1016/j.simpat.2016.09.001.
6. Bombinski S, Kossakowska J and Jemielniak K. Detection of accelerated tool wear in turning. *Mech Syst Signal Process* 2022; 162: 108021.
7. Ahmed YS, et al. Effect of built-up edge formation during stable state of wear in AISI 304 stainless steel on machining performance and surface integrity of the machined part. *Materials* 2017; 10: 1230. DOI: 10.3390/ma10111230.
8. Courbon C, Fabre D, Methon G, et al. A 3D modelling strategy to predict efficiently cutting tool wear in longitudinal turning of AISI 1045 steel. *CIRP Ann Manuf Technol* 2021; 70: 57–60.
9. Liu Q, Xu J and Yu H. Experimental study on the influence of tool wear on the cutting process of Ti6Al4V. *J Phys Conf Ser* 2021; 1838: 012026. DOI: 10.1088/1742-6596/1838/1/012026.
10. Liu Z, Yue C, Li X, et al. Research on tool wear based on 3 D FEM simulation for milling process. *J Manuf Mater Process* 2020; 4: 121. DOI: 10.3390/jmmp4040121.
11. Zhu K and Zhang Y. A generic tool wear model and its application to force modelling and wear monitoring in high speed milling. *Mech Syst Signal Process* 2019; 115: 147–161.
12. Li X, Wang Z, Yang S, et al. Influence of turning tool wear on the surface integrity and anti-fatigue behavior of Ti1023. *Adv Mech Eng* 2021; 13: 1–12. DOI: 10.1177/16878140211011278journals.sagepub.com/home/ade.
13. Binder M, Klocke F and Lung D. Tool wear simulation of complex shaped coated cutting tools. *Wear* 2015; 330–331: 600–607. DOI: 10.1016/j.wear.2015.01.015.
14. Yadav RK, Abhishek K and Mahapatra SS. A simulation approach for estimating flank wear and material removal rate in turning of Inconel 718. *Simul Model Pract Theory* 2015; 52: 1–14.
15. Zhang G and Guo C. Modeling flank wear progression based on cutting force and energy prediction in turning process. *Procedia Manuf* 2016; 5: 536–545. DOI: 10.1016/j.promfg.2016.08.044.
16. Bloul B, Bourdim A, Hamou S, et al. Geometric analysis of the influence of perpendicularity of a spindle axis of the milling machine on the surface quality. *Adv Mech Eng* 2017; 9: 1–8. DOI: 10.1177/1687814017700831journals.sagepub.com/home/ade

Appendix

Notations

Symbol	Designation	Units
V_B	Flank wear	mm
V_c	Cutting speed	m/min
f_a	Feed speed	mm/turn
α	Angle perpendicularity	radian
$D_1 \dots D_n$	Tooth order 1 ... tooth order n	
r_e	Nose radius of the cutting tool	mm
x_i	Coordinate: abscissa	mm
z_i	Coordinate: ordinate	mm
θ_{max}	Maximum angle of contact position	radian
θ_{min}	Minimum angle of contact position	radian
h_{rmax}	Maximum depth of path	mm
BUE	Built-up edge	
a_e	Tool engagement	mm
a_p	Depth of cut	mm
t	Machining time	min
$k, a_1, a_2, a_3, a_4, a_5$	Unknown linear system factors	