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Modeling of the Phenomena of Tool Wear, Cutting Time Reeel by Approach of the Plans of Experiments in the Case of Shoot Dry

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ABSTRACT

In machining operations, the progressive wear of cutting tools poses a major challenge for manufacturers. It directly affects the quality of produced units, dimensional accuracy, tool life, and manufacturing costs. If not detected in time, this wear can lead to surface finish deterioration, production defects, and unplanned machine tool downtime.

Address these challenges, this study proposed the development of an intelligent system capable of monitoring the wear state of turning tools-specifically during the longitudinal turning of S400N steel using uncoated P20-grade carbide inserts-in a simple, cost-effective, and automated manner. The developed solution used year ESP32 microcontroller that is paired with an MPU6050 vibration sensor and an ACS712 current sensor. These sensors enable the real-time collection of data reflecting tool behavior during machining.

Alongside signal acquisition, an image of the carbide insert is captured using a smartphone after each machining test. This image is then analyzed by a computer vision algorithm developed using OpenCV to automatically identify the wear band and calculate sti width, denoted as VB. [1] and [2].

Applying the Design of Experiments (DoE) method will enable the creation of a mathematical model to predict cutting tool wear based on the experimental results, and subsequently determine the optimal parameters to minimize cutting tool degradation gold gradual wear [3].

Design of Experiments facilitates the effective organization of tests across various research fields and in industrial settings [4].

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KEYWORDS: *Modeling, tool wear, real-time, OpenCV, design of experiments, turning.*

1. INTRODUCTION

The continuous improvement of quality, productivity and competitiveness represents today a major challenge for manufacturing companies [5]. In this context, the machining operations are essential in the manufacture of mechanical parts, in particular in the sectors of automotive, aerospace, energy and general mechanical engineering. Among the many parameters that influence the performance of a machining process, the state of the cutting tool remains one of the most important.

Indeed, the gradual wearing of the tool changes the cutting conditions and may cause an increase in mechanical stresses, excessive vibration, deterioration of the surface quality as well as a reduction of the dimensional accuracy of the parts produced.

In the industrial practice, the monitoring of tool wear is often done by visual inspections, or by using specialised equipment such as optical microscopes. Although these methods have good accuracy, they usually require the machine to stop and the intervention of a qualified operator. Thanks to the recent progress of artificial intelligence, it is now possible to develop systems capable of automatically monitoring the status of a tool during its operation.

The main objective is to implement an experimental platform at a low cost to monitor the wear and tear of

a turning tool in the case of cutting orthogonal by combining the acquisition ofdata from embedded sensors and the automatic analysis of images. This study aims to :

- Automatically measuring the width of the wear band VB from images of the carbide insert;
- Develop a dashboard that is interactive, allowing the analysis of the results of the experiments in order to Prepare the data necessary for the implementation of a model predictive maintenance approach of design of experiments.

2. APPROACH EXPERIMENTAL STUDY

To characterize the wear of cutting tools, several standard parameters have been proposed in the scientific literature. Among these, the width of the wear band flank**,** denoted as **VB**, is the criterion most commonly used to follow the evolution of the degradation of a cutting edge during machining. This parameter corresponds to the average width of the zone worn observed on the opposite flank of the tool and is generally expressed in millimeters (mm).

Due to its ease of measurement and its good representation of the state of wear, the parameter VB is widely adopted in the trials of life turning tools [6], [7] and [8].

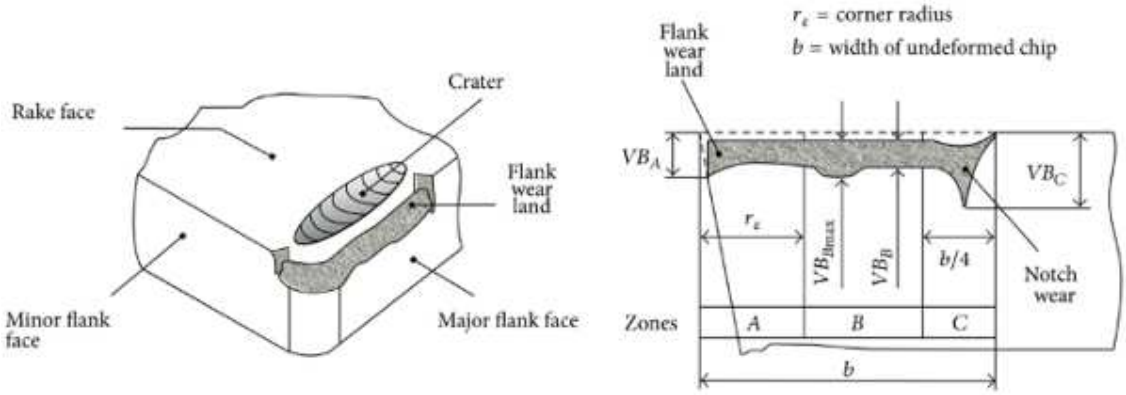


Fig. 2.1. Geometric definition of the width of flank wear (VB) according to the standard ISO 3685.

The figure 2.1 above shows the different areas of measurement (A, B, C, and N), the average width of the wear band (VB), the maximum width (VBmax) and the main geometrical parameters used to characterize the gradual wearing of a turning tool [6] and [7].

2.1. Driving experiences

The tests were carried out on a conventional lathe-type GALLIC 14, whose technical characteristics are given in table 2.1. The choice of this conventional machine also has a scientific interest. In fact, contrary to the modern machines equipped with integrated systems of monitoring, it allows to assess the effectiveness of a system of external supervision based on sensors at low cost.

This approach corresponds to the goals of Industry 4.0, aimed at making existing facilities more intelligent thanks to the addition of digital solutions. This choice is also motivated by its availability, simplicity of operation as well as its ability to reproduce the classic conditions for a process of shooting

Table 2.1: technical Specifications of the conventional lathe GALLIC 14. [9]

Characteristic	Value
Type of machine	GALLIC 14
engine Power	4,5 - 6,5 kW
Range of Speeds of rotation	32 – 1600 tr/min
maximum Diameter machinable	110 mm
Distance between centers	100 mm
Range of feed rates	of 0.05 – 1.6 mm/rev

2.2. Component material

The choice of the material to be machined is a crucial step in the conduct of experimental tests, because the mechanical and metallurgical properties of the room directly influence the behavior of the cutting process, the formation of the chip, the forces generated as well as the mechanisms of wear of the tool.

In the framework of this study, the material chosen for this study is a steel S400N, provided in the form of test tubes cylindrical (Figure 2.2). According to the standard ISO 15608, this steel belongs to the group 2.1**,** which

includes the grain steels for having undergone a heat treatment. It is characterized by a yield strength (Re) ranging between 360 and 460 N/mm2**,** while its maximum resistance to tensile strength (Rm) is about 650 N/mm2**.**



Fig. 2.2: test tube steel S400 N fixed on the cock of the tower [workshop Mechanics I. S. T. A / Kinshasa]

Table 2.2: chemical Composition indicative of the steel S400 N used in the study [ISO 15608]

Elements	Symbols	- Content (%)
Carbon	(C	0,25
Silicon	S_i	0,60
Mn	Mn	1,70
Molybdenum	Mo	0,70
Sulfur	S	0,045
Phosphorus	P	0,045
Copper	Cu	0,40[b]
Nickel	N_i	a 0.5[b]
Chrome	C_r	0,3
Niobium	Nb	0,05
Titanium	T_i	0,05

2.3. Door insert

The door plate is used to secure or hold the insert rigidly to perform the work [10]. The tool holder used in this study is designated according to the international standard ISO 5608 with a codification which allows to determine its characteristics :

Table 2.3: Characteristics of the door-plate [11].

Designation	Brand	α_0	γ_0	K_p	Material tool holder
PSLCR 2525 M12	Sandvik	7°	- 7°	90°	42 $CrM_0$4

With :

P: indicates the mode of fixation of the plate by center hole with the help of a lever;

S: indicates the shape of the plate (square);

L: this is the angle of attack of the tool holder relative to the workpiece;

C: clearance angle;

R: meaning of cut;

2525: determine the dimensions of the body of the tool holder (height and width) that is to say, 25 as height and 25 as the width;

M: length tool holder (code M = 150 mm);

12: length of the cutting edge in (mm).



Fig. 2.3: Door plate PSLCR 2525 M12

2.4. Plate

For all the work on machine tools, the material of the tool must be harder than the workpiece. The testing of the operation of turning were carried out using a tool carbide insert removable not coated with a square-shaped shade P20 represented in figure 2.4, with like components: tungsten (W), titanium carbide (TiC), tantalum , niobium (Nb) and a connecting element between the carbide particles (size 0.2 to 1μm) it is a tool that displays the properties of the high conservation of temperature (up to 1000°C) .Its hardness is of the order of 80 to 90 HRC with R_m = 1400 N/mm2 [12]



Fig. 2.4: Insert carbide removable non-coated shade P20 [11] [12]

2.5. Measurement of flank wear of the tool (smart system)

In a process of industrial monitoring, the measurement of the wear allows you to determine the real state of the tool and to predict the optimal time of replacement. A poor estimate of this evolution may result in either a premature change of the tool, resulting in an increase in the costs of production, that is an excessive use leading to a degradation of the quality of the parts, or to a sudden rupture of the cutting edge, [13] and [14].

In the framework of this study, the measurement of flank wear is essential for the validation of the intelligent system developed. The goal is to automatically obtain a quantitative estimate of the state of the carbide insert from images acquired after the turning operations.

The technique used for the measurement of flank wear is based on Computer Vision which is a set of methods that allows a computer system to extract useful information from images or video sequences. It combines several scientific domains such as image processing, artificial intelligence, pattern recognition and numerical analysis.

The general principle is based on the acquisition of a digital image of the active area of the tool using the camera of a smartphone placed in any shooting conditions are controlled. This image is then transferred to an application developed in **Python**is a programming language, where it is processed using the library**OpenCV**.

Several image processing techniques are successively applied, including the conversion to grayscale, the filtering of the noise, contrast enhancement, segmentation of the wear area, the edge detection and the extraction of geometric features. The width of the wear band is then calculated automatically after a calibration step to convert the dimensions measured in pixels in the actual values expressed in millimeters [1] [15]. The developed system consists of two complementary systems:

- The acquisition, which is responsible for collecting data from the machining process with the components listed in table 2.4 below;

Table 2.4: components of The acquisition system

Component	Function
ESP32	Acquisition and transmission of data
MPU6050	Measurement of vibrations
ACS712	current-Measuring engine
built in Wi-Fi	Communication with the PC
Smartphone	Acquisition of the images of the pack

- Under-treatment system used for the signal processing, the analysis of the images, the automatic measurement of the VB, the display of the results, shown in figures 2.5 to 2.9 below.



Fig. 2.5: Card ESP32 used in the acquisition system



Fig. 2.6: Sensor inertial MPU6050 used for the measurement of vibration



Fig. 2.7: Procedure for image acquisition of the carbide insert after machining[Workshop Mechanics I. S. T. A/Kinshasa]

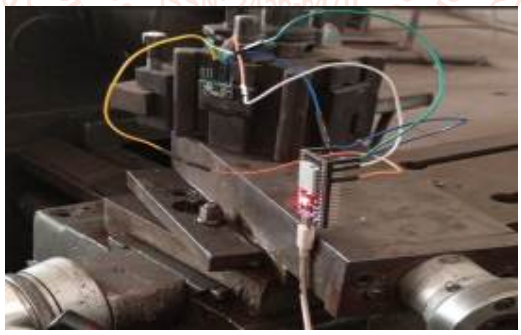


Fig. 2.8: Implantation of the sensor MPU6050 on the conventional lathe [Mechanical Workshop I. S. T. A /Kinshasa]



Fig. 2.9: Communication with PC [Mechanical Workshop I. S. T. A /Kinshasa]

2.6. The cutting parameters used

For the choice of the cutting parameters, the following criteria were considered: the quality of the machine, the power of the machine, the field of work that has impact on the choice of the material of the tool (cutting tool), the quality of the material of the tool must be harder than the workpiece, the machining operation (turning dry), the shape of the tool (geometric shape of the tool relative to its characteristic angles) [16].

The cutting parameters used in relation to the order of the trials are shown in table 2.5 below :

Table 2.5: The cutting parameters used

N° Trials	Vc (mm/min)	f (mm/tr)	ap (mm)
1	80	0,4	1
2	250	0,4	1
3	80	0,8	1
4	250	0,8	1
5	80	0,4	2
6	250	0,4	2
7	80	0,8	2
8	250	0,8	2

With: Vc (cutting Speed), f (ahead of the tool), ap (depth of cut)

2.7. Image analysis for the automatic measurement of the width of the wear band (VB)

The proposed approach is based on computer vision. The principle is to acquire digital images of the carbide insert after each test for longitudinal turning, to be applied in a processing chain developed inOpenCV, in order to automatically detect the wear strip and measure the width.

The approach has several advantages. It first allows to automate the measurement of **VB**, reducing the errors that are related to the visual assessment of the operator. It also improves the repeatability of measurements through the application of a protocol of acquisition is the same for all trials. Finally, it facilitates the integration of the results in the intelligent system developed, where the values of **VB** are directly associated with the data transmission of vibration and electrical recorded during the machining process.



Fig. 2.10: complete String of image analysis for the automatic measurement of the width of the wear band VB)

3. PRESENTATION, INTERPRETATION AND DISCUSSION OF RESULTS

Although the process of shaping material by removal of material is used compared to other manufacturing processes mechanical aspects of the modeling and simulation of the phenomena involved in the process are very important.

These aspects are especially complex because of the diversity of the phenomena of mechanical and physico-chemical during the formation of the chip, such as: adhesion, abrasion, plastic deformation of the main ridge of the cutting tool, the corrosion [5].

For a good organization of the tests and experimental results, the simulation method approach of design of experiments will be used in this article. This model allows to obtain the maximum information with the minimum of experience [3]. It will rely on a plan of experiments factorial complete 2^3 using the technique of Screening. It is a technique of selection or screening. It is a word of anglo-saxon Screening. [17].

This technique allows to determine the items that have a lot of influence over others. The meaning of 2^3 is simply to clarify that we have 3 factors and 2 levels of the factors (high and low). The model used will be represented by the form :

$$Y_{mod} = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_{12}x_1x_2 + a_{13}x_1x_3 + a_{23}x_2x_3 + has_{123}x_1x_2x_3 \quad (3.1)$$

With:

Y_{mod}: Value of the response obtained from the tests in relation to the wear front-end;

x_1 : Value of the factor 1 compared to the experience matrix corresponding to the factor cutting speed Vc (m/min);

x_2: the Value of the factor of 2 compared to the experience matrix corresponding to the factor the tool advance (mm/rev);

x_3: the Value of the factor of 3 compared to the experience matrix corresponding to the factor depth of cut of the tool (mm).

a_0: This value is the average of the responses

a_1: the effect of factor 1

a_2: the effect of the factor 2

a_3: the effect of the factor 3

a_{12}: the interaction between the effect of factor 1 and factor effect 2

a_{13}: the interaction between the effect of factor 1 and factor effect 3

a_{23}: the interaction between the effect of the factor of 2 and the effect of the factor 3

has_{123}: the interaction between the effect of factor 1, the effect of the factor of 2 and the effect of the factor 3.

After experiments, the full factorial design 2^3 is shown in the table 3.1 below.

Table 3.1. Matrix of experiment and response of VB after each Test

N° Test	Factor 1 Vc (mm/min)	Factor 2 f (mm/tr)	Factor 3 ap (mm)	Wear VB (mm)
1	80	0,4	1	0,23
2	250	0,4	1	0,31
3	80	0,8	1	0,29
4	250	0,8	1	0,39
5	80	0,4	2	0,28
6	250	0,4	2	0,37
7	80	0,8	2	0,35
8	250	0,8	2	0,48

3.1. Presentation analysis and discussion of results

By applying the concepts of the plans fractional [4] and [17],it brings us back to the basic plan $2^{k-1} = 2^{3-1}$ that is to say 4 experiments, with 3 factors.

A plan fractional is generally represented by [17]: 2^{k-r}

With: 2 which represents the two levels;

k : the number of factor;

r: the reduction factor applied to the factorial design original

The plans fractional derivatives are applied only if k has a value greater than 2 [17].

3.1.1. The combined influence of the cutting speed and feed on tool wear

Figure 3.1 shows the curves of iso-response describing the variation of the width of the band on flank wear (**VB**) as a function of the cutting speed (**Vc**) and feed (**f**), for a depth of cut kept constant at 1 mm.

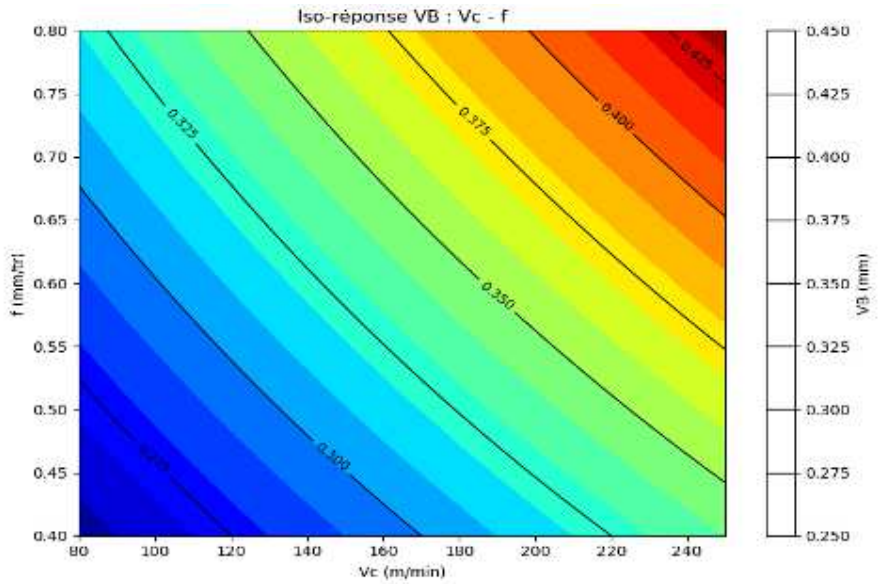


Fig. 3.1: the Curves of iso-response of the width of the wear band (VB) as a function of the cutting speed (Vc) and feed (f).

The curves of iso-response are relatively widely spaced in the region corresponding to low values of the cutting parameters, indicating a low sensitivity of wear. On the other hand, they become closer when the cutting speed exceeds approximately 200 m/min, and the advance is greater than 0.6 mm/rev, which translates to a more rapid increase of the wear (figure 3.2). Under the experimental conditions used, the cutting speed appears as the dominant factor, while the advance plays a role in amplification of wear and tear when the two parameters are increased simultaneously.

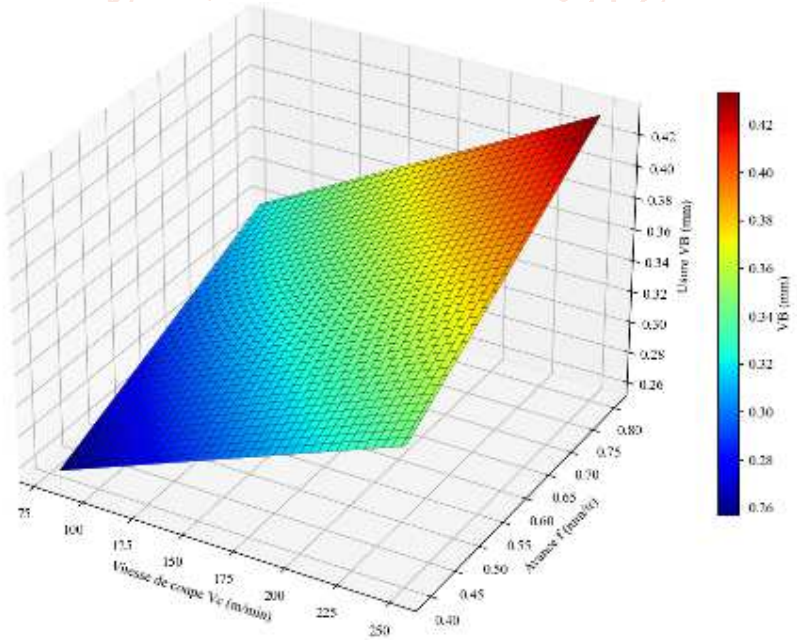


Fig. 3.2: response Surface 3D of VB as a function ofVcand f

3.1.2. The combined influence of the cutting speed and depth of cut on tool wear

The curve of iso-response highlights a steady increase in the wear when the cutting speed increases. This trend is accentuated by the increase of the depth of cut. The areas of low values of**VB** are located in the lower-left part of figure 3.3, corresponding to the low cutting speed and low depths password. Conversely, the highest values are located in the upper right, where the two parameters reach their maximum levels.

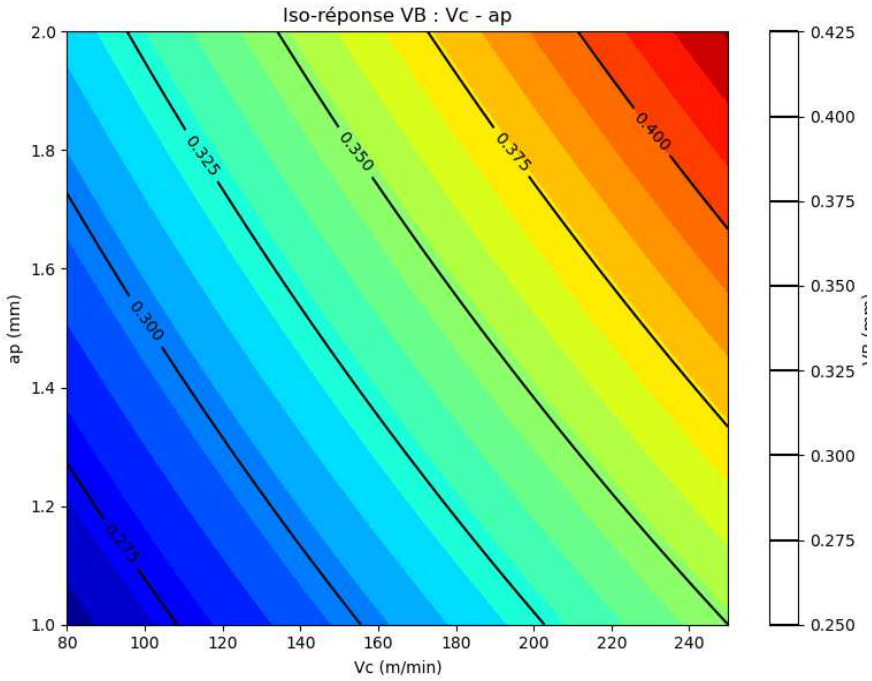


Fig. 3.3: the Curves of iso-response of the width of the wear band as a function of the cutting speed(Vc) and the depth of cut (ap)

The effect of the cutting speed remains the more marked, as evidenced by the orientation of the curves of iso-response. An increase of the depth of cut also causes an increase of the wear and tear, but with an intensity of more moderate. This observation is explained by the fact that a depth most important is increasing the section of the chip, resulting in an elevation of the cutting forces, the contact stresses and the power dissipated at the level of the cutting edge.

The interaction between **Vc** and **ap** is evidence of a cumulative effect: when these two parameters are increased simultaneously, the temperature and mechanical stress in the cutting zone become more important, thus accelerating the formation of the wear strip.

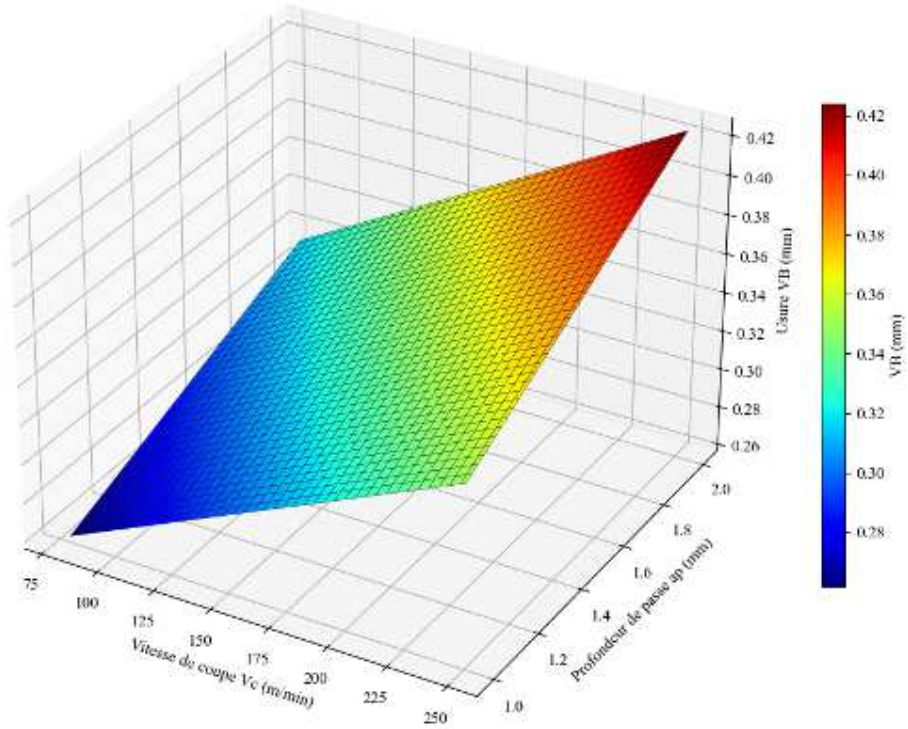


Fig. 3.4: response Surface 3D (VB = f (Vc, ap))

These results confirm that the choice of cutting speed moderate associated to a depth suitable constitutes a good compromise to reduce the wear of the tool while maintaining a satisfactory productivity.

3.1.3. The combined influence of the advance payment and of the depth of cut of the tool

The distribution of the curves shows that the wear increases gradually when the advance and the depth of cut (figure 3.5) increase simultaneously. Color variations indicate growth at relatively regular**VB** on the whole experimental area. The curves remain relatively widely spaced, reflecting a more gradual development of wear compared to previous figures.

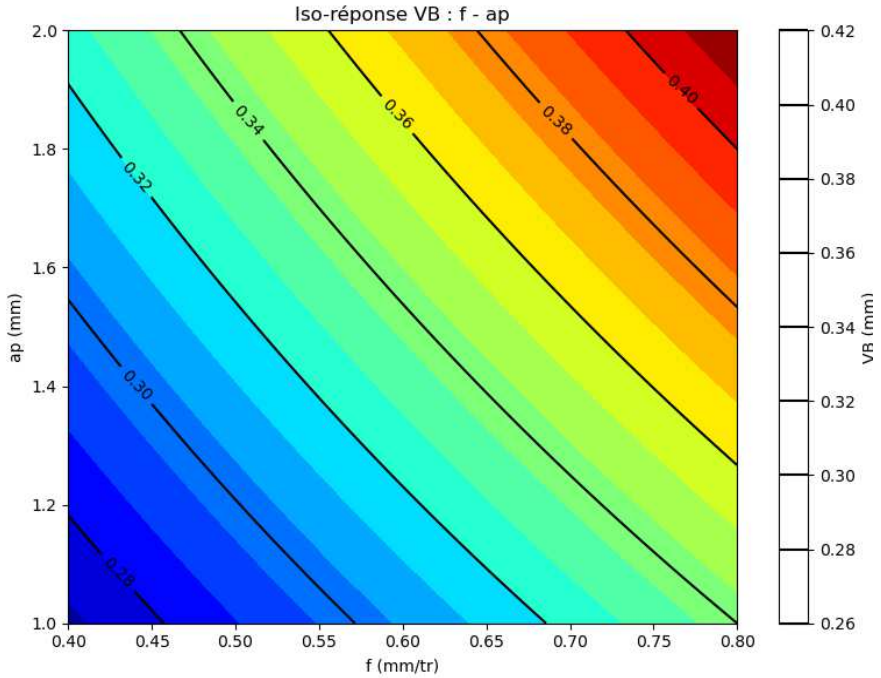


Fig. 3.5: Curves of iso-response of the width of the wear band (VB) as a function of the feed(f) and depth of cut (ap)

This trend is explained by the fact that the increase of the advance increases directly the thickness of the chip, as well as the efforts of cut, while a depth most important is increasing the amount of material removed in each pass (figure 3.6). These two parameters help to intensify the mechanical constraints applied to the tool and promote the onset of flank wear. However, the gradients observed are less pronounced than those associated with the cutting speed, which indicates that in the area studied, the combined effect of the advance payment and of the depth of cut remains lower than that involving the cutting speed.

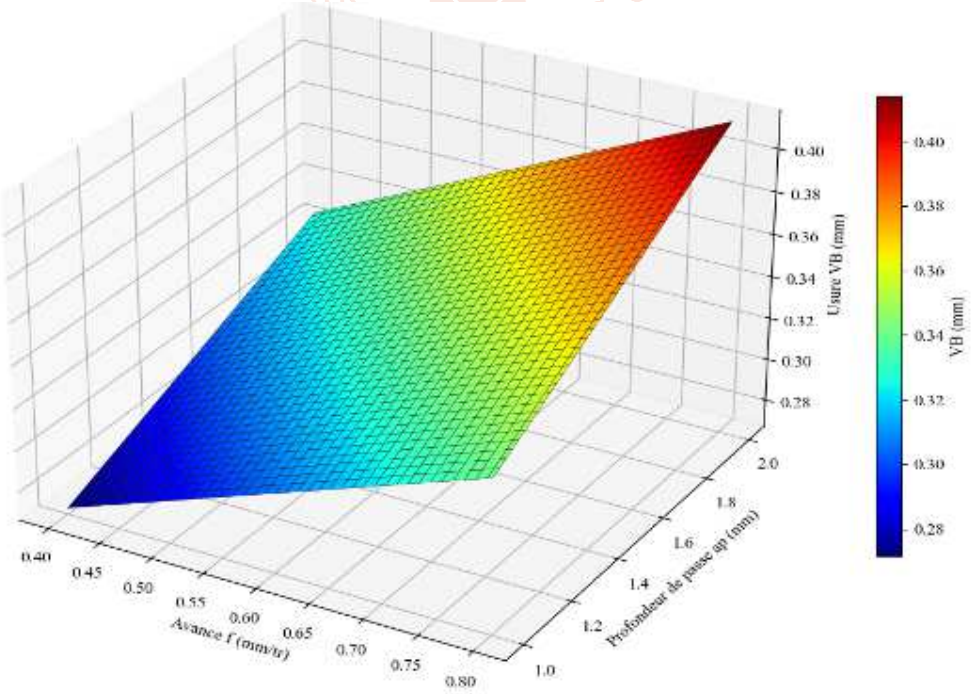


Figure 3.6: response Surface 3D of VB as a function of f andap

4. CONCLUSION

The study of the three cards of iso-response shows that the cutting parameters do not have the same influence on the evolution of the width of the wear band **VB**. Among the factors studied, **the speed** of cut is shown as the parameter the more influential, which is in agreement with the mechanisms tribological and thermal described in the literature. The increase of **Vc** causes an elevation of the temperature in the cutting zone, thus accelerating the wear phenomena by abrasion, diffusion and oxidation.

The'advance and the depth of cut also contribute to the increased wear due to the increase of the cutting forces and mechanical stresses applied to the cutting edge. However, their influence is more gradual and occurs mainly when they are combined with high cutting speeds.

In the experimental area studied, the conditions most favourable to limit the wear and tear correspond to a low cutting speed (80 m/min), a low advance (0.4 mm/rev) and a low depth of cut (1 mm). Conversely, the toughest conditions, associated with the maximum values of the three parameters (250 m/min**,** 0.8 mm/rev and 2 mm), lead to the highest values of **VB**. These results demonstrate the ability of the regression model to describe the interactions between the cutting parameters and constitute a relevant basis for the optimization of machining conditions and the development of an intelligent system of monitoring the wear of the cutting tools.

The results obtained demonstrate the feasibility of a low-cost solution dedicated to the monitoring of the condition of the cutting tools and open up interesting perspectives for the future development of systems of predictive maintenance in industrial environments.

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