Determination of a Mathematical Model of Taper Wear for a Longitudinal Surfacing Operation

L. ZOUAMBI[1,2,*], M. BOURDIM[1,3], M. DJILALI BEIDA[1,3], S. KERROUZ[1,3], W. OUDAD[4],
[1]Department of mechanical engineering, Ahmed Zabana University, Algeria
[2]Laboratory of Mechanics and Physics of Materials, Sidi-bel-Abbes, Algeria,
ORCID: 0000-0002-1732-5237
[3]Industrial Engineering and Sustainable Development Laboratory, Relizane, Algeria
[4]Department of mechanical engineering, University of Ain Temouchent, Algeria

Abstract— Turning is one of the most widely used machining processes in the mechanical engineering industry. Thus, the choice of optimal cutting parameters (cutting speed, feed and depth of cut) is very important in order to ensure a better surface condition of the machined parts and the life of the cutting tools, which requires great relationship with the wear of the tool-part interface. The result of a good choice of cutting conditions can be seen by a reduction in this wear. During machining, the geometric shape and the physical state of the tool are modified by the combined action of the cutting forces and by the temperature reached by the cutting edge. These modifications which gradually increase with the duration of machining are commonly grouped under the term wear of the tool. They appear on the active part of the tool. In this work, we propose an optimization method allowing determining a mathematical model of the wear and tear by applying the experiment plan. This model highlights the relationship between the elements of the cutting regime (cutting speed, feed and depth of passes) and the responses studied (Wear in clearance).

Keywords— Machining, Cutting forces, Temperature. Wear.

I. Introduction

Wear is a complex set of phenomena which are difficult to interpret, leading to the emission of debris with loss of mass, dimension, shape, and accompanied by physical and chemical transformations of surfaces [1-2]. Wear involves a large part of chemical reactions; chemically inert surface layers can sometimes be more resistant to friction than hard layers, especially in the presence of aggressive media.

Wear, according to the standard definition, is the progressive loss of material from the active surface of a body as a result of the relative movement of another body on this surface [3-4]. In the formation of the chip, the cutting part of the tool in relative movement with the workpiece and the chip is subjected to very intense mechanical and thermal stresses which cause its wear and its rapid deterioration [5]-[8].

Observation of the active part of the tool reveals forms of wear. We can meet various forms of wear depending on the nature of the materials present (tool-part), according to the external conditions due to the environment and finally according to the cutting regime, see Fig 1. The quality of the part produced in machining depends mainly on the state of the cutting tool used.

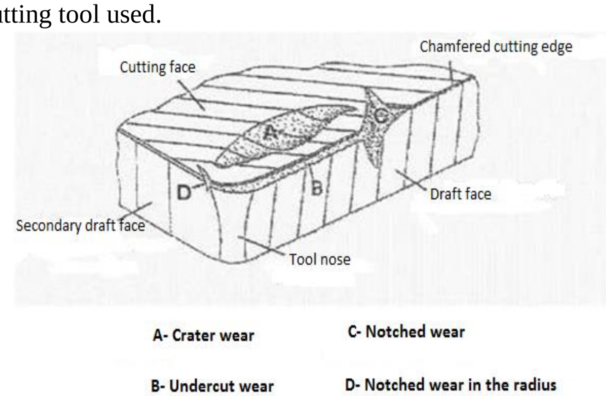


Fig. 1. Wear patterns of a machining insert [13]

The latter is exposed to damage during the machining operation due to friction with the workpiece and the chips generated [9]-[12]. Hence the advantage of predicting its lifetime during machining before degradation of the machining process.

II. Equipment Used

The machining was carried out on a TOS model SN40C universal lathe in the technological hall of the Abou Bekr Belkaid Tlemcen Algeria University, whose electric motor power is 6.8 kW; Fig 2:

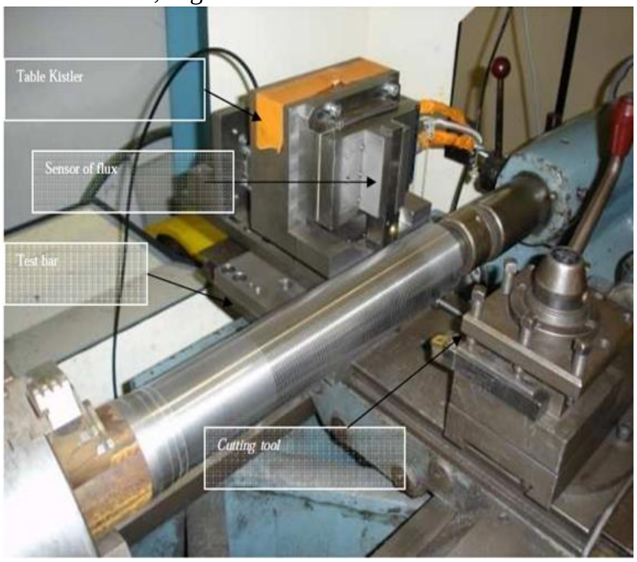


Fig. 2. General view of the machining

The material machined is highly alloyed steel X155CrMoV12 [4]. The parts are in form of full cylinders with a diameter D = 57 mm and a length L = 240 mm.

The chemical composition is given in Table 1.

TABLE I. CHEMICAL COMPOSITION OF THE PART

% C	%Mn	%Si	%Cr	%Mo	%V	%P	%S
1 ,55	0,51	0,22	3	0,8	0,34	0,032	0,035

The cutting tool used is a cubic boron nitride tool CBN of the TNMG 16 04 08 type and a tool holder for designation SOGIMO 9020W3K10 having the following geometry, see Fig 3.

$\psi = 90°$; $\alpha = 6°$; $\gamma = -6°$; $\lambda = -6°$; $r_\varepsilon = 0.8$mm

With:

Ψ: edge direction angle

α: draft angle,

ɤ: cutting angle,

r_ε: tool nose radius.

Fig. 3. Brochure and brochure holder

The measurement of pad wear is carried out with a microscope Fig 4. To allow the measurement, this microscope is equipped with a crossed displacement table, with an accuracy of 1µm.

Fig. 4. Microscope used

III. MATHEMATICAL MODELING OF THE REPONSE

In the absence of any information on the function, which links the response to the factors, we a priori give ourselves a law of evolution whose most general formulation is as follows (1):

$$y = f(x_1, x_2, x_3, \dots, \quad x_n) \qquad (1)$$

This function is too general and it is customary to take a limited development from Taylor-Mac Laurin, that is to say an approximation. If the derivatives can be considered as constants, the previous development takes the form of a polynomial of greater or lesser degree (2):

$$y = a_0 + \sum a_i x_i + \sum a_{ij} x_i x_j + \sum a_{ii} x_i^2 + \cdots .. \qquad (2)$$

y: Is the quantity in which the experimenter is interested; that's the answer or the size of interest.

x_i : Represents a level of factor i.

x_j: Represents a level of factor j.

a_0, a_i, a_{ij}, a_{ii}: Are the coefficients of the polynomial.

This model is called the a priori model or the postulated model. The established models are valid forecast models in the field of study, an area which must always be specified. They are not theoretical models based on physico-chemical or mechanical laws. In some rare cases, it is possible to use known theoretical physical laws [5].

IV. PRESENTATION OF THE PROBLEM

We know that the experiment plan method allows us to meet our requirements, in order to predict the effect of cutting conditions on wear and to model the studied response, and also in order to reduce the number of experiments and describe the influence of cutting conditions under the influence of factors.

Testing	Vc m/mn)	*f* (tr/mn)	ap (mm)	Wear V_B (mm)
1	220	0.08	2.6	0.166
2	220	0.08	1	0.143
3	90	0.08	2.6	0.096
4	90	0.08	1	0.071
5	220	0.25	2.6	0.290
6	220	0.25	1	0.191
7	90	0.25	2.6	0.111
8	90	0.25	1	0.085

For this, we are interested in the influence of cutting parameters on wear. It is therefore judicious to apply a modeling of the behavior by the method of the experimental plans.

The model which will be obtained later will facilitate the prediction of wear at any point in the experimental field. The aim of this method is to see the variation in wear as a function of three cutting speed parameters (Vc, *f*; ae).

These represent the input parameters according to Fig 5. By means of a mathematical model that will be established, the system response represents the wear and tear, which is represented by "V_B".

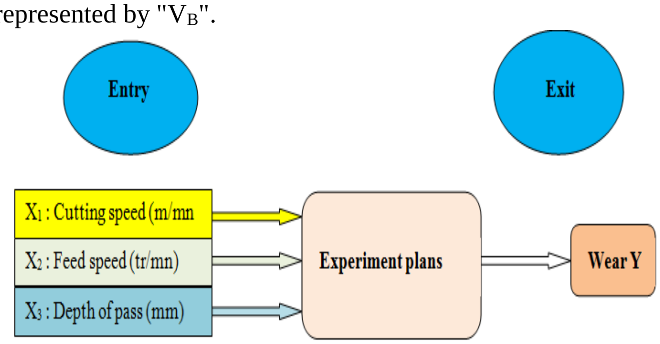


Fig. 5. Operating model of the test parameters

V. PROPOSAL OF A MODEL

The wear of the cutting tool can be expressed in terms of cutting parameters, i.e. cutting speed, feed and cutting depth. In its general form (3):

$$Y = (Vc, f, ap) \quad (3)$$

Optimization of wear was carried out using the experimental design software Design Expert 7.

This program allows us to perform the following tasks:

- Calculation of effects and interactions between factors (therefore the mathematical model),
- Statistical analysis and coefficients of the model,
- Iso-responses and response surfaces,
- Level curves of the prediction error function… ..etc.

Taking into account the objectives to be achieved, it is imperative to establish the list of experimental responses to study and then make a proposal for a mathematical model. For this, we must first obtain real answers by an experimental test carried out at the Abou Bekr Belkaid university in tlemcen, see Table 2.

TABLE II. UNDERCUT WEAR VALUES (VB) ACCORDING TO THE CUTTING PARAMETERS

With:
Vc: cutting speed,
f: Feed speed,
ap: Depth of pass.

VI. MATHEMATICAL MODELING

After having estimated the coefficients of the model, we can now establish the mathematical model (4): it is a polynomial of the first degree, which links the response to the factors. The developed model can be used effectively to predict wear during a longitudinal surfacing operation; it takes the form (4):

$$Y = a_0 + a_1.x_1 + a_2.x_2 + a_3.x_3 + a_{12}.x_1.x_2 + a_{13}.x_1.x_3 + a_{23}.x_2.x_3 + a_{123}.x_1.x_2.x_3 \quad (4)$$

With:
Y: represents the value of the response
x_1: represents the value read in the experience matrix (factor 1 value)
x_2: represents the value read in the experience matrix (factor 2 value)
x_3: represents the value read in the experience Omatrix (factor 3 value)
a: The average value of the effect of the three factors
a_1: The effect of cutting speed
a_2: The effect of the advance
a_3: The pass depth effect
a_{12}: The interaction between a_1 and a_2
a_{13}: The interaction between a_1 and a_3
a_{23}: The interaction between a_2 and a_3
a_{123}: The interaction between a_1; a_2 and a_3

The mathematical model of wear and tear V_B is expressed as follows (5):

$$VB = -1{,}23932.10^{-3} + 5{,}82906.10^{-4}.x_1 + 0{,}11389.x_2 + 0{,}039624.x_3 - 5{,}55556.10^{-4}.x_1.x_2 - 2{,}64957.10^{-4}.x_1.x_3 - 0{,}26966.x_2.x_3 + 3{,}11966.10^{-3}.x_1.x_2.x_3 \quad (5)$$

This mathematical model adequately represents the phenomenon studied in the experimental field by researchers in mechanical engineering. The advantage of modeling the response is to be able to then calculate all the responses in the field of study without being obliged to carry out experiments.

From this model, we can obtain response and iso-response curves illustrating the variation in wear as a function of the cutting parameters (Vc, *f*, ap).

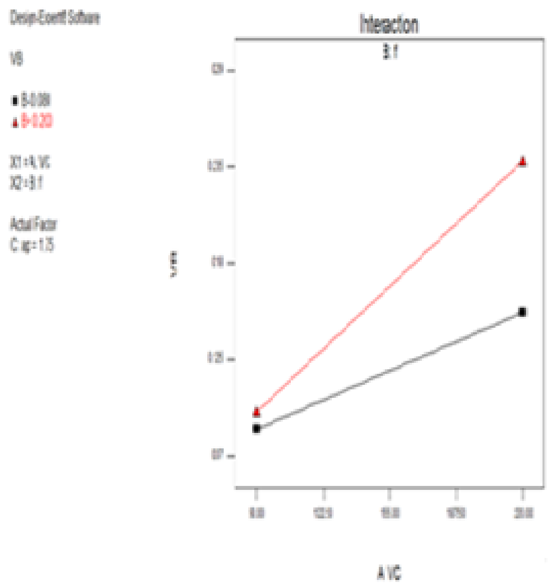
The Fig 6, below illustrates the interaction and the effect of cutting parameters on wear V_B.

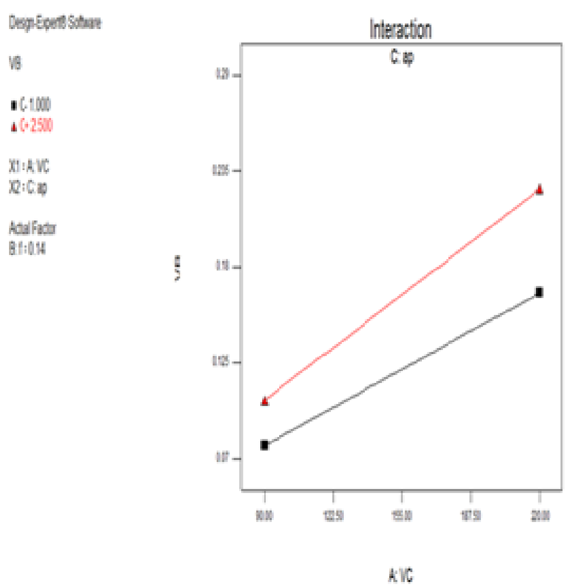
The iso-responses clearly show that regardless of the feed rate chosen, increasing the cutting speed increases wear. As an example Fig 7, for an advance of 0.19 mm/rev, and a speed of 206.76m/min, we obtain a wear of 0.220mm.

The Fig 7, above illustrates the result of our mathematical model, from these results obtained, we can see that the cutting speed is the most influencing factor on the increase in wear.

In order to be able to verify the model developed by the experiment plan method, another step was made, this last one consists in defining the mathematical equation, the interactions between the factors and the response surfaces by MATLAB, whose algorithm is as follows, see Fig 8.

The results obtained from those of the responses and those of iso- responses expressing the variation in wear as a function of the cutting parameters are presented in Fig 9 and Fig 10.





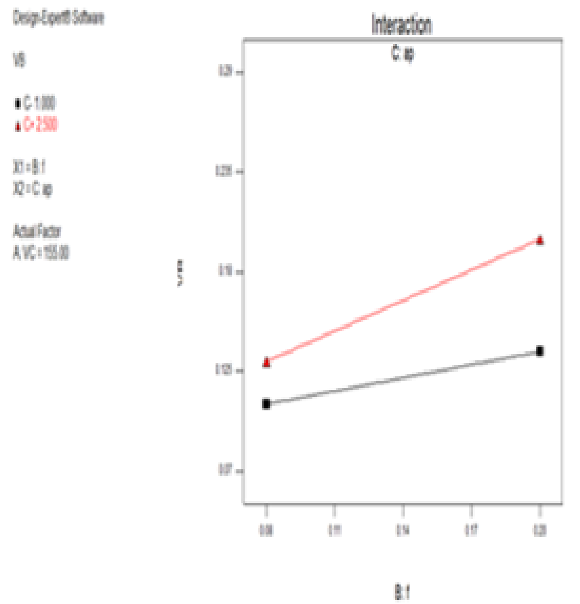
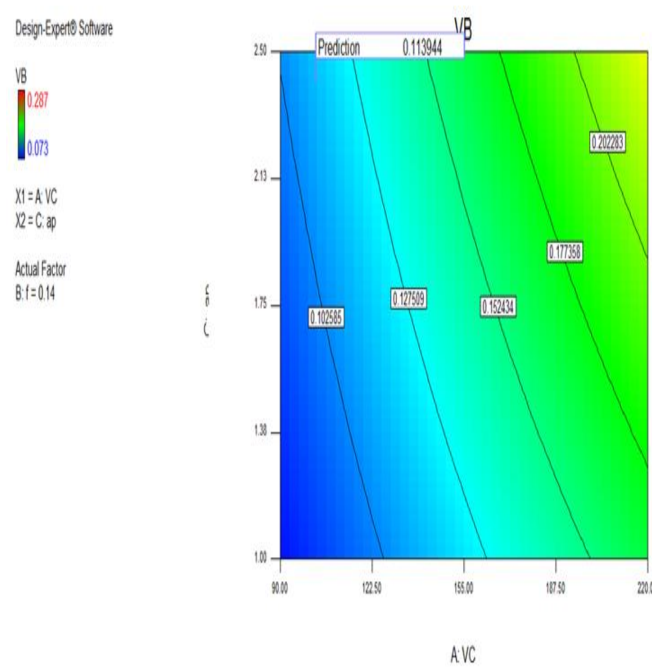


Fig. 6. Effect and interaction of cutting conditions on wear

The effect of the cutting speed, the feed rate and the depth of pass on the undercut wear VB of the tool is clearly shown in Fig 9 and Fig 10.

The results found by MATLAB programming, show that the method used is favorably compared with the experimental results,

The effect of process parameters on wear is demonstrated. This process is verified by the method of experiment plans and by MATLAB programming and overall, the results are the same.



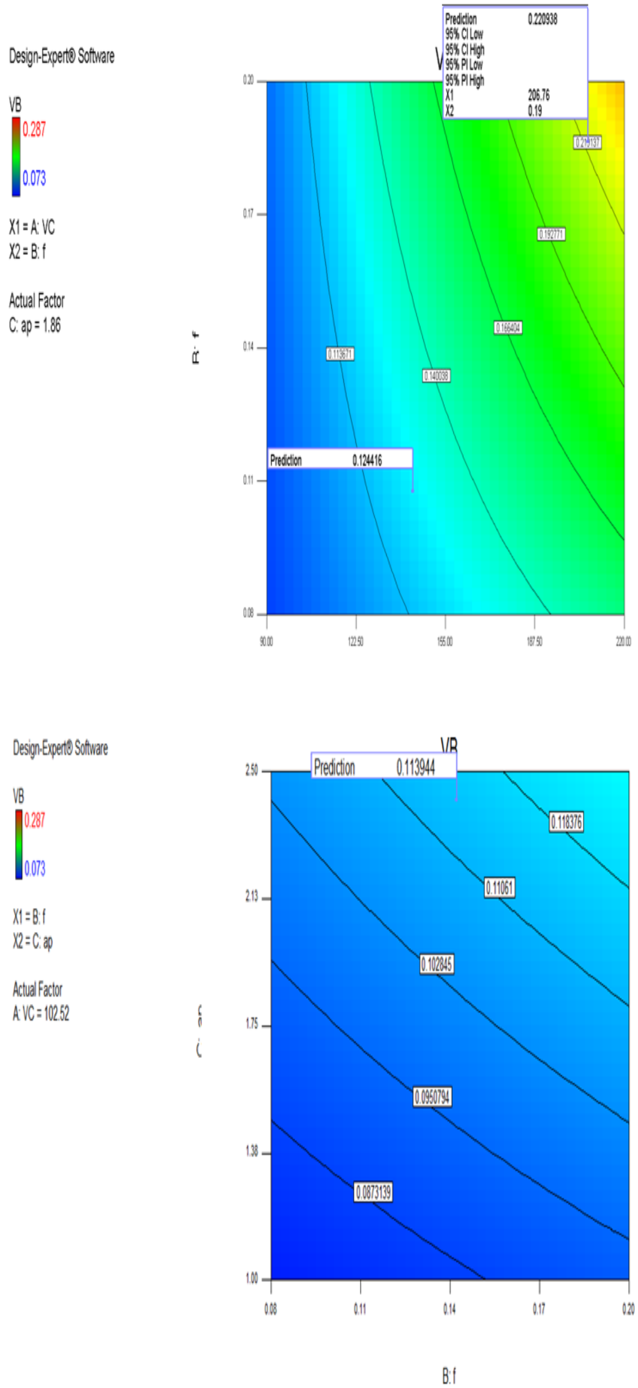


Fig. 7. Iso-response curves expressing the variation in wear as a function of the cutting parameters

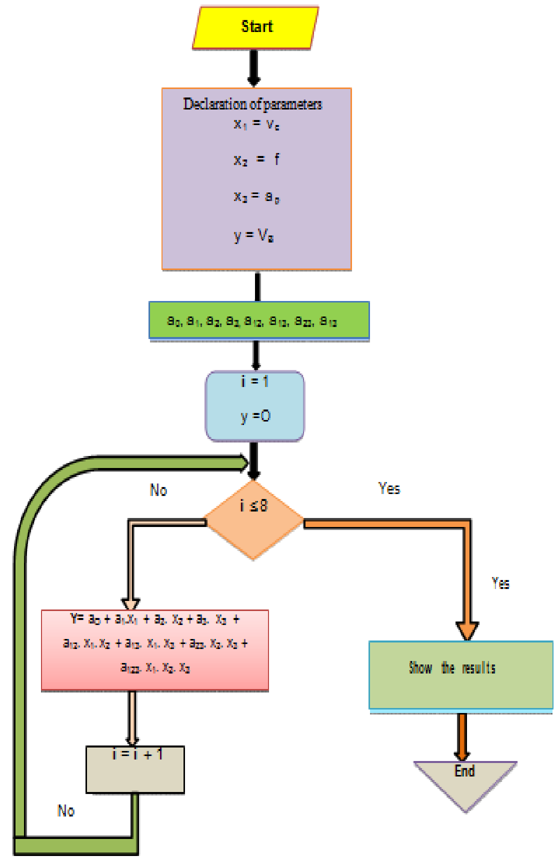
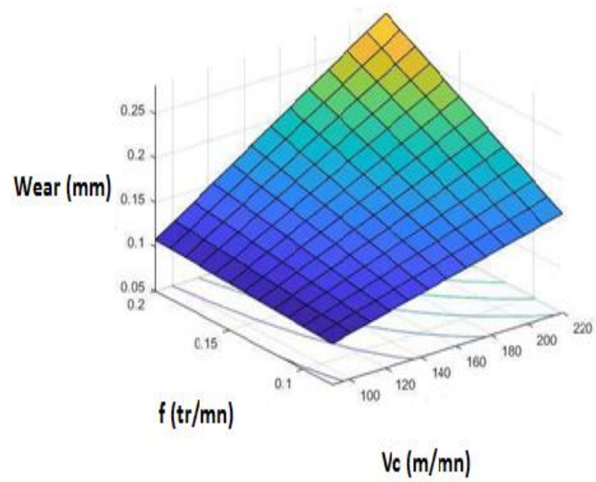


Fig. 8. Verification algorithm



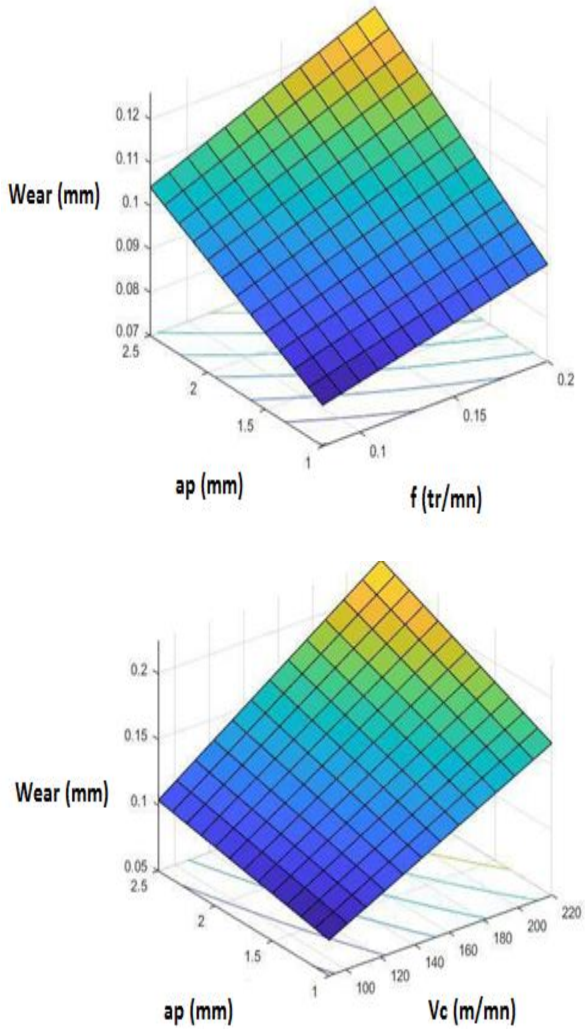
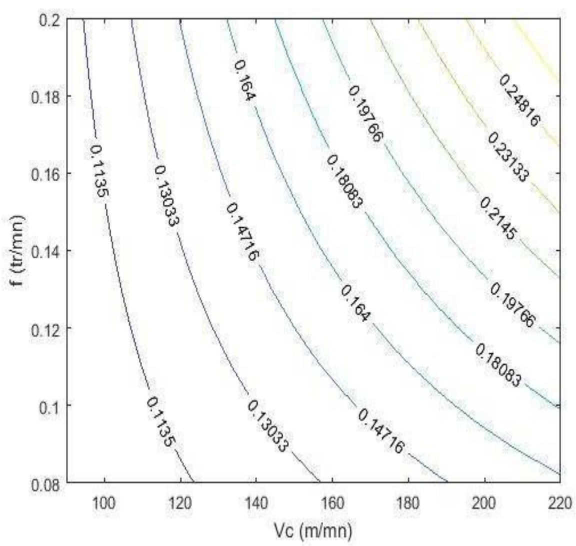
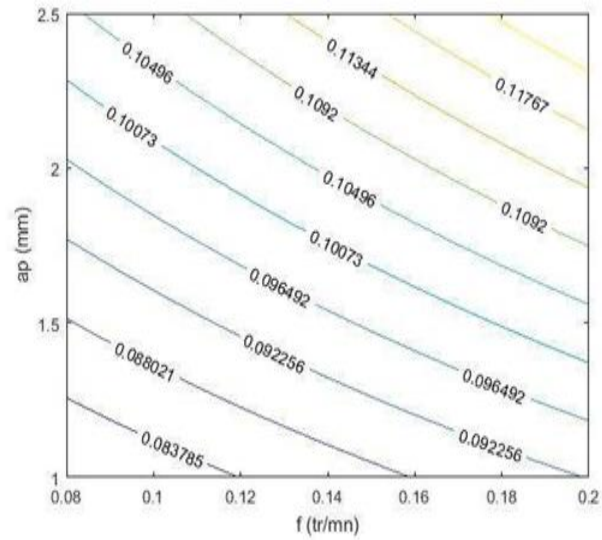


Fig. 9. Response curve expressing the variation in wear as a function of the cutting parameters





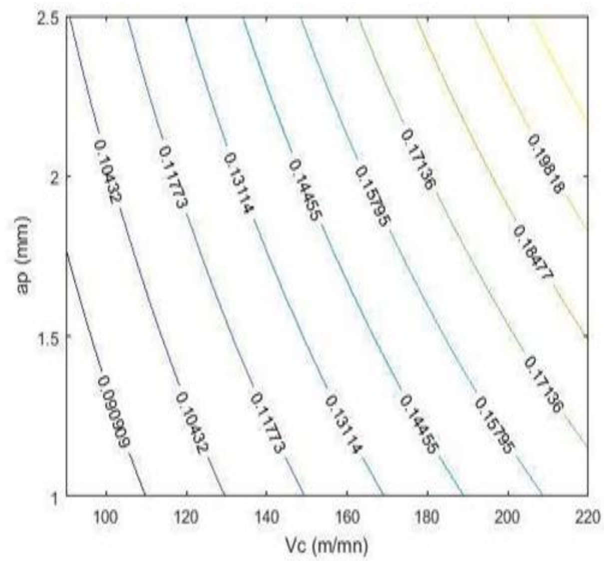


Fig. 10. Iso-response curves expressing the variation in wear as a function of the cutting parameters

VII. CONCLUSION

After estimating the coefficients, the mathematical model can reliably predict VB wear during a longitudinal surfacing operation developed on the basis of experimental observations.

The analytical expression thus developed connecting each studied response to influencing factors and interactions was established to highlight the correlations which link them with the different graphic representations.

The results obtained allow us to note that:

Increasing the cutting speed increases wear.

The interaction of the three parameters, that is to say the increase in cutting speed, feed and depth of cut results in an increase in the response which is wear.

The cutting speed is the most influencing factor on the response.

Low speeds reduce wear.

Finally, the objective of this work concerns the selection of the optimal set of cutting parameters in order to obtain low wear values of the cutting tool during the longitudinal surfacing operation of the highly alloyed steel. This will help increase the life of the cutting tool.

REFERENCES

[1] [1]M.Dieye, Comportement dynamique du systéme piece-outil–machine(POM)en rectification plane passé profonde(Dynamic behavior of the part-tool-machine (PTM) system in deep past surface grinding). PhD thesis, National School of Arts and Crafts, Centre de Metz, 2002.

[2] D.Kara-Ali, Contribution à la modélisation Coupe–paramètres d'usinage à l'aide de la Méthode de Traitement de Données par Groupe (Contribution to Cut – machining parameters modeling using the Group Data Processing Method), University of Abou Bekr Belkaid Tlemcen, 2013.

Y. Ohbuchi and T. Obikawa, Adiabatic shear in chip formation with negative rake angle. International Journal of Mechanical Sciences, Vol.47, N.9, 2005, pp.1377–1392.

[3] M.Bourdim, Contribution à l'étude de l'intégrité de l'état de surface usinéé en tournage dur (Contribution to the study of the integrity of the machined surface finish in hard turning), PhD thesis, National Higher School of Technological Education of Oran, 2013.

[4] I. Yahiaoui, Les plans d'expériences Initiation à la construction et l'analyse des plans Factoriels complets à deux niveaux et du plan composite centré (Experimental designs Initiation to the construction and analysis of complete Factorial designs at two levels and the centered composite design), PhD thesis , University of Bedjaia, 2015.

[5] M.G.Vigier, Pratique des plans d'experience, organizational editions, pp 190, 1988.

[6] J. Goupy, Plans d'experiences pour surfaces de réponse (Experimental plans for response surfaces), Edition Dunod, 2001.

[7] M. Abdelkrim, Etude de l'influence de la température de coupe dans l'usure Des outils et sur les caractéristiques métallurgiques des Alliages usinés (Study of the influence of cutting temperature on tool wear and on the metallurgical characteristics of machined alloys), PhD thesis, University of Batna 2008.

[8] http/googleweblight.com/httpwww.cours-et-exercices.com/2016 choix des matériaux de l'outil usinage.

[9] A. Maurel-Pantel, Etude expérimentale et modélisation par éléments finis du procédé de fraisage (Experimental study and finite element modeling of the milling process), Université de Franche-Comté, 2009.

[10] J. VERGNAS, Usinage, Technologie et Pratique, Génie Mécanique DUNOD, ISBN 2-04- 011186-7, Bordas, Paris 1982.

[11] ROCDACIER, Cours sur le Tournage - Usinage Cours Technologie (Turning - Machining Course Technology Course), Paris 2001.