Integrity study of the machined surface quality in hard turning

Mokhtar Bourdim[1*], Djilali Beida Maamar[1], Khadidja Boualem[1], Ahmed Maizia[1]

[1]Department of Mechanical Engineering, Faculty of Science and Technology, University of Relizane, 48000, Algeria

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Abstract— Since their appearance, machining techniques have undergone multiple improvements. The processes of shaping materials by removing material have been constantly questioned in order to stay in step with industrial requirements, whatever economic or ecological. Today, the manufacturing engineer must therefore be able to answer a multitude of questions in order to quickly produce parts of the required quality and at low cost.

Hard turning is a process that can be described as standard in a number of sectors such as the production of bearing steel 100Cr6 chrome with a hardness of 62 RC, but also turning auto parts steel chromium-manganese cemented hardened gears as 27MnCr5 a hardness of 62 RC. The technical and economic feasibility of machining parts such harshness was made possible thanks to the use of new tool materials with a very high hardness and high chemical stability at high temperatures, such as cubic boron nitride CBN, and with the arrival of new machine tools with significant stability and high precision. Hard turning allows today to produce high-quality surfaces from competing in many cases, operations traditionally reserved for rectification. High speed machining has also showed its competitiveness in applications such as turning parts for gearboxes and drivesystems in hardened materials. This article is a contribution to the study of the integrity of the machined surface in hard turning.

Keywords— Hard turning, cutting forces, rectification, roughness, productivity, precision, integrity.

I. Introduction

THE search for ever better productivity in metal cutting is a major concern. This improvement is based more or less directly on the in-depth study of the physical mechanisms and laws governing this process. It is therefore an essential objective; its interest cannot be overshadowed by the development of new machining means or new control and programming techniques even if these latter points also participate in the development of high-speed manufacturing..., new materials, increased demands imposed by new products and increasing cost levels imply the implementation of new production methods. More generally, rationalization efforts are focused on reducing manufacturing times and improving quality. These strategies call on several techniques which we cite here increasing the speed of machining. The hard turning allows today, to produce surfaces of very high quality coming to compete, in many cases, operations traditionally reserved for rectification. It is so current to end in roughness Ra, of the. order of 0.2 microns and in dimensional quality precision 6.

The rectification has long been the main finishing operation accepted for hardened steel. However, in the name of reducing costs and increasing productivity, hard turning increasingly replaces this operation. This technique reduced the cost of removing parts grinding operations. Roughing and finishing of parts on the same machine actually drastically reduce downtime machine, machining time and in progress. It was the advent of tools such as coated micro-grain carbides, ceramic, cubic boron nitride and diamond that made the industrial exploitation of this technology possible [1].

The latter had relatively high performance in turning for their substitution for rectification operations [2-4]. We can also say that the hard turning is a promising process which interests many industrialists for the advantages that it presents from the point of view of productivity and flexibility. To master the process and make profitable its industrial use, it is necessary to study the integrity of the manufactured surface state and the laws which govern its variation according to the manufacturing parameters.

The selections of the cutting material as well as its elements of the cutting regime are a delicate phase. Therefore the experimenter is confronted with the choice of an experiment plan allowing him to know the influence of variables tested on the phenomenon studied and to propose the elements necessary for the understanding of the elements of the cutting regime on the holding and the surface finish produced during the machining of the treated steel.

II. STATE OF SURFACE

The capacity of a piece in a given function depends on a set of conditions; the surface state of a piece is going to depend thus:

- Of its material.
- Of the mode of manufacturing.
- Of the surface treatment.

If we control with a machined surface profilometer, we obtain a graph whose image is given by the figure below cons. Deformations are of course very much enlarged.

These defects are equally distributed on the surface of both sides of the line ox, we retain the most influential report on the roughness: Ra. Consider a local cut of the perpendicular machined surface to the grooves machining, see Fig.1.

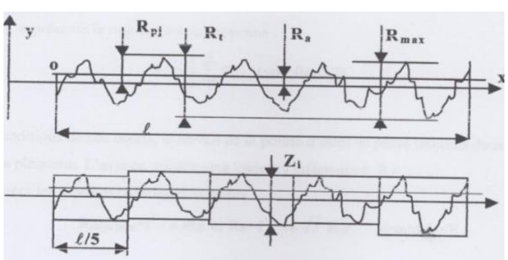

Fig. 1 Roughness criteria [5]

It has been shown that the cutting conditions used very significantly affect the integrity of functional surfaces. There are several factors that affect the quality and integrity of the machined surface in hard turning. These factors can be classified on the material of the work piece (hardness, metallurgical properties ...) and cutting parameters.

The quality of the machined surface is affected by the hardness and material properties [6, 7]. It is shown that the surface roughness decreases with increasing hardness of the piece, but this affects the hardness of life of the tool plate CBN [8].Cutting parameters have significant effects on the quality of the surface obtained by hard turning, increasing the cutting speed and the decrease of the advance can reduce roughness and improve the quality of the surface.

Koenig investigated the effect of the edge geometry and noted that a chamfered cutting edge alters roughness compared to a sharp edge. Theile et al proved that the geometry of the tool of the cutting tool has a very important impact on the residual stress, a rounded edge favors the appearance of compressive stresses [9]. On the other hand, the radius of the tip of the tool has a considerable effect on the integrity of the surface obtained. In fact, the roughness is inversely proportional to the radius of the plate.

The cutting geometry is an interesting factor in the study of the surface quality in hard turning given its influence on the wear of the tool which affects the machined surface. The CBN content influences the quality of the machined surface; in general, a tool with a low CBN content (50 to 70% of boron nitride) has better performance [10-12].

III. EXPERIMENTAL MODEL

We present in this section the experiment methodology and the equipment used to study the evolution of the surface obtained by hard turning of hardened steels.

In order to better understand the evolution of roughness, two materials were tested. The specimens machined material is highly alloyed steel according to french standard NF A 35-590 (Table 1).

Table 1: Materials specimen

Machined materials
X100 CrMoV5
X155 CrMoV12

The hardening of the first steel is obtained by quenching at 940°C followed by tempering at 280°C in order to obtain a hardness of 62 HRC, on the other hand for the second steel it is obtained by oil quenching followed by an income at 400 ° C which led to a hardness of 56 HRC slightly less hard than the first material.

The cutting tool is formed of a triangular plate irreversible titanium carbide coated type TNMG 16 04 08, and a tool holder of 90 ° 20W3K10 SOGIMO designation has a following geometry:

$$\psi = 95^\circ \; ; \alpha = 6^\circ \; , \gamma = -6^\circ$$

Cutting was performed without lubrication on a conventional lathe brand "TOS TRENCIN" with a power of 6, 8 Kw, see Fig. 2 of hall technological Aboubekr Belkaid University of Tlemcen.

In hard turning, machines that are extremely rigid, powerful and accurate are recommended. Any weakness in the machine tool system causes a faster degradation of the tool and the surface. In general, a tour suitable for machining hard materials should have a certain number of characteristics seen in previous chapters, the tower used proved sufficiently rigid to identify the behavior of the tool. During testing we have not observed the phenomenon of chatter, but few vibrations were observed in higher chip sections.

In order to study the impact of different cutting parameters, each test is repeated four times. The procedure involves Table 2: Design of experiments data

(a) factors first material

making passes Roughing varying cutting conditions and measuring the value of roughness Ra. The principle of measurement of the surface condition is the movement of a probe on the work piece. The transverse displacement of the tip determines the profile of the machined surface.

Fig. 2 Overview of machining

The adapted cutting conditions were chosen according to the requirements and recommendations of Sandvik through using the method of experimental design. Cutting speed Vc (variable) = (100, 150, 200 and 250) m / min Feed rate f (variable) = (0.08, 0.1, 0.16 and 0.2) mm / rev Depth of cut ap (variable) = (0.05, 0.1, 0.2 and 0.4) mm.

Experiment plans are excellent tools for structured experimentation. Several authors have already used experimental designs to solve manufacturing problems, in particular to study the influence of cutting conditions on the surface finish of parts, or on the life of the cutting tool.

The experimental design method makes it possible both to reduce the number of trials, and to study a very large number of factors, but also to detect possible interactions between factors. We choose to apply this method to discover the effects and interactions of different machining parameters on the topography of machined surfaces without increasing the number of tests.

The experience plan includes:

Input data which are the explanatoryvariables (3 variables): ·

- Vc (cutting speed), ·
- ap (depth of cut), ·
- f (feed).

Output data which are the variables explained (or parameters: 2):

- Roughness (Ra), ·
- Cutting forces (Fx, Fy and Fz).

Table 2 gives the factors of the experimental design as well as their levels.

Table 2: Design of experiments data

(a) factors first material

Level	Factors		
	Cutting speed (Vc m / min)	Feed f (mm / rev)	Depth of cut ap(mm)
+1	250	0.2	0.4
-1	150	0.08	0.05

Level	Factors		
	Cutting speed (Vc m / min)	Feed f (mm / rev)	Depth of cut ap(mm)
+1	200	0.2	0.4
-1	100	0.08	0.05

(b) factors second material

IV. ROUGHNESS EXPERIMENTAL RESULTS

The results represented in the (Table 3) give the value of the roughness for the two types of materials tested.

X1 = Vc (m/min) = 100 and 250.

X2 = f (mm/rev) = 0, 08 and 0, 2.

X3 = ap (mm) = 0, 05 and 0, 4.

Table 3: Roughness values first machined material

(a) first machined material

N Test	X_1 = Vc (m/mn)	X_2 = f (mm/rev)	X_3 = ap (mm)	Ra_1 (µm)	Ra_2 (µm)	Ra_3 (µm)	Ra_{1moy} (µm)
1	-	-	-	0,23	0,34	0,43	0,333
2	+	-	-	0,32	0,20	0,19	0,236
3	-	+	-	0,89	0,88	0,91	0,893
4	+	+	-	0,63	0,84	0,90	0,790
5	-	-	+	0,64	0,65	0,70	0,663
6	+	-	+	0,44	0,44	0,48	0,453
7	-	+	+	0,69	0,91	0,21	0,603
8	+	+	+	0,56	0,70	0,56	0,606

(b)second machined material

N Test	X_1 = Vc (m/mn)	X_2=f (mm/rev)	X_3 = ap (mm)	Ra_1 (µm)	Ra_2 (µm)	Ra_3 (µm)	Ra_{1moy} (µm)
1	-	-	-	0,33	0,32	0,33	0,326
2	+	-	-	0,36	0,34	0,35	0,350
3	-	+	-	0,85	0,87	0,86	0,860
4	+	+	-	0,90	0,84	0,90	0,880
5	-	-	+	0,70	0,69	0,70	0,696
6	+	-	+	0,45	0,48	0,48	0,470
7	-	+	+	0,88	0,91	0,51	0,766
8	+	+	+	0,66	0,67	0,68	0,670

In order to be able to determine the mathematical model of roughness, let's use the results of the following (Table 4) taken from the experimental designs using mathematical regression and excel developed by relizane of university.

Table 4: Roughness mathematical configuration

(a) configuration first material

N°	X_1	X_2	X_3	X_1X_2	X_1X_3	X_2X_3	$X_1X_2X_3$	Y			Y moy	S_i^2	$\hat{Y}$	$\hat{Y}-Y_{moy}$
1	-1	-1	-1	1	1	1	-1	0,23	0,34	0,43	0,33	0,010033333	0,345	0,00013611
2	1	-1	-1	-1	-1	1	1	0,32	0,2	0,19	0,24	0,005233333	0,243333	4,4444E-05
3	-1	1	-1	-1	1	-1	1	0,89	0,88	0,91	0,89	0,000233333	0,901667	6,9444E-05
4	1	1	-1	1	-1	-1	-1	0,63	0,84	0,9	0,79	0,0201	0,8	0,0001
5	-1	-1	1	1	-1	-1	1	0,64	0,65	0,7	0,66	0,001033333	0,6	0,00401111
6	1	-1	1	-1	1	-1	-1	0,44	0,44	0,48	0,45	0,000533333	0,498333	0,002025
7	-1	1	1	-1	-1	1	-1	0,69	0,91	0,21	0,60	0,128133333	0,646667	0,00187778
8	1	1	1	1	1	1	1	0,56	0,7	0,56	0,61	0,006533333	0,545	0,00380278
										Σ	4,58	0,171833		0,01207

entrez les donnez suivantes

N= 8 m = 3 t = 1,68

résultats

Y moy = 0,5725

1	0,5725	β_0 =	0,5725	S_{reg}^2	0,02	21,5E-3
1	-0,050833333	β_1 =	-0,0508	$S(\beta_i)$ =	0,029916	
1	0,150833333	β_2 =	0,1508	$\Delta(\beta_i)$ >=	50,3E-3	
0	0	β_3 =	0,0092	$S^2_{rés}$ =	3,64E-05	
0	0	β_{12} =	0,0258	F_{exp} =	0,0016947	
0	0	β_{13} =	-0,0008	L=	4	
1	-0,1275	β_{23} =	-0,1275			
0	0	β_{123} =	0,0275			

(b) configuration second materiel

N°	X_1	X_2	X_3	X_1X_2	X_1X_3	X_2X_3	$X_1X_2X_3$	Y			Y moy	S_i^2	$\hat{Y}$	$\hat{Y}-Y_{moy}$
1	-1	-1	-1	1	1	1	-1	0,33	0,32	0,33	0,33	3,33333E-05	0,350833	0,00058403
2	1	-1	-1	-1	-1	1	1	0,36	0,34	0,35	0,35	1E-04	0,3725	0,00050625
3	-1	1	-1	-1	1	-1	1	0,85	0,87	0,86	0,86	0,0001	0,8825	0,00050625
4	1	1	-1	1	-1	-1	-1	0,9	0,84	0,9	0,88	0,0012	0,904167	0,00058403
5	-1	-1	1	1	-1	-1	1	0,7	0,69	0,7	0,70	3,33333E-05	0,640833	0,00311736
6	1	-1	1	-1	1	-1	-1	0,45	0,48	0,48	0,47	0,0003	0,479167	8,4028E-05
7	-1	1	1	-1	-1	1	-1	0,88	0,91	0,51	0,77	0,049633333	0,775833	8,4028E-05
8	1	1	1	1	1	1	1	0,66	0,67	0,68	0,67	0,0001	0,614167	0,00311736
										Σ	5,02	0,0515		0,00858

entrez les donnez suivantes

N= 8 m = 3 t = 1,68

résultats

Y moy = 0,6275

1	0,6275	β_0 =	0,6275	S_{reg}^2	0,01	6,4E-3
1	-0,035	β_1 =	-0,035	$S(\beta_i)$ =	0,0163777	
1	0,166666667	β_2 =	0,1667	$\Delta(\beta_i)$ >=	27,5E-3	
0	0	β_3 =	0,0233	$S^2_{rés}$ =	2,456E-05	
0	0	β_{12} =	0,0158	F_{exp} =	0,0038148	
1	-0,045833333	β_{13} =	-0,0458	L=	5	
1	-0,099166667	β_{23} =	-0,0992			
0	0	β_{123} =	0,01667			

By exploiting the results of multiple linear regressions, we can directly derive the global mathematical model of the roughness for the two machined materials, considering only the significant regression coefficients, it is written as follows.

$$Ra1 = 0{,}57 - 0{,}05X1 + 0{,}15X2 - 0{,}12X2X3$$

$$Ra2 = 0{,}62 - 0{,}03X1 + 0{,}16X2 - 0{,}04X1X3 - 0{,}09X2X3$$

Let's fix now alternately each input variable (X1, X2 and X3) at its average value, and examine the impact this has on the distribution of output (Ra) the mathematical model becomes:

$$Ra1(X2, X3) = 0{,}57 + 0{,}15X2 - 0{,}12X2X3$$

$$Ra1(X1, X3) = 0{,}57 - 0{,}05X1$$

$$Ra1(X1, X2) = 0{,}57 - 0{,}05X1 + 0{,}15X2$$

$$Ra2(X2, X3) = 0{,}62 + 0{,}16X2 - 0{,}09X2X3$$

$$Ra2(X1, X3) = 0{,}62 - 0{,}03X1 - 0{,}04X1X3$$

$$Ra2(X1, X2) = 0{,}62 + 0{,}03X1 + 0{,}16X2$$

Now, let's replace each variable by its tru scale, the final mathematical model is written as follows:

$$Ra1(f, ap) = 0{,}57 + 0{,}15f - 0{,}12f.p$$

$$Ra1(Vc, ap) = 0{,}57 - 0{,}05Vc$$

$$Ra1(Vc, a) = 0{,}57 - 0{,}05Vc + 0{,}15a$$

$$Ra2(f, ap) = 0{,}62 + 0{,}16X2 - 0{,}09X2X3$$

$$Ra2(Vc, ap) = 0{,}62 - 0{,}03X1 - 0{,}04X1X3$$

$$Ra2(Vc, f) = 0{,}62 + 0{,}03X1 + 0{,}16X2$$

To facilitate data analysis, a number of curves have been drawn to better understand the variation in roughness as a function of the different variables (Cutting speed, Feed speed and Depth of pass), from the reduced mathematical model to two dimensions and three dimensions by Surfer software which allows curves to be produced from a digital model. This software allows we to create grids that will interpolate irregular data from points X1, X2, X3 in order to order them.

Now plot the curves defining features of the variation in roughness for different cutting parameters (cutting speed, feed rate and depth pass).

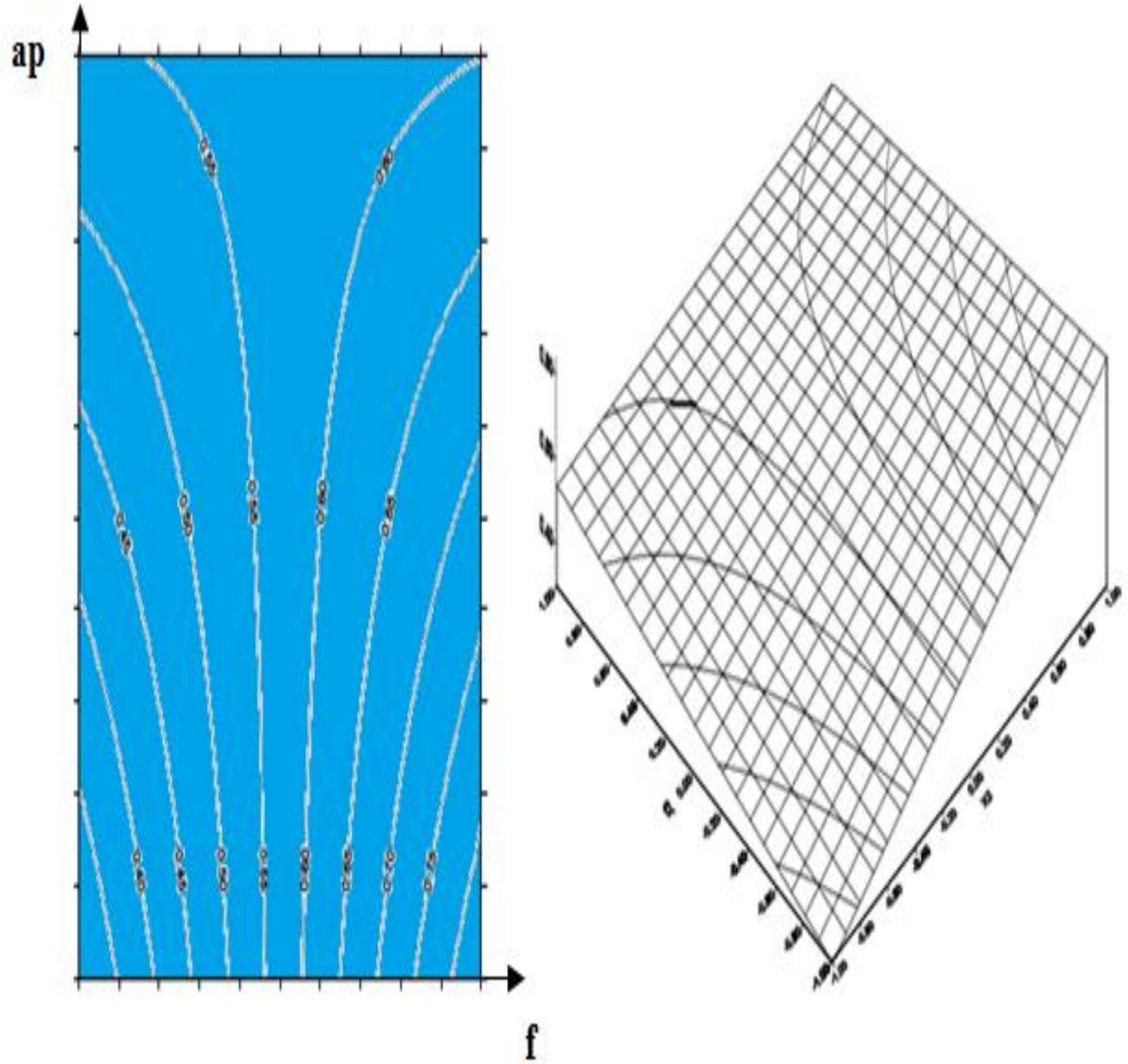

Fig. 3 Evolution of the roughness of the first material function of the feed rate and depth of cut

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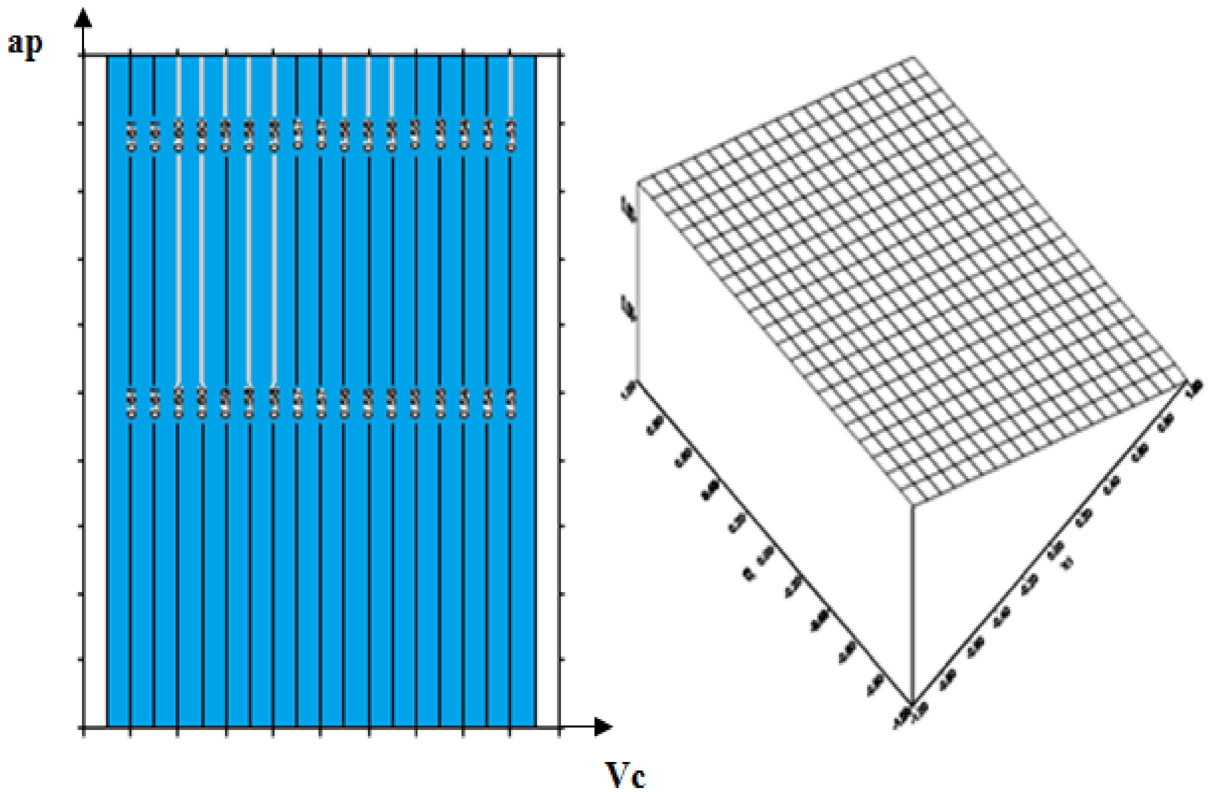


Fig. 4 Evolution of the roughness of the first material function of the cutting speed and depth of cut

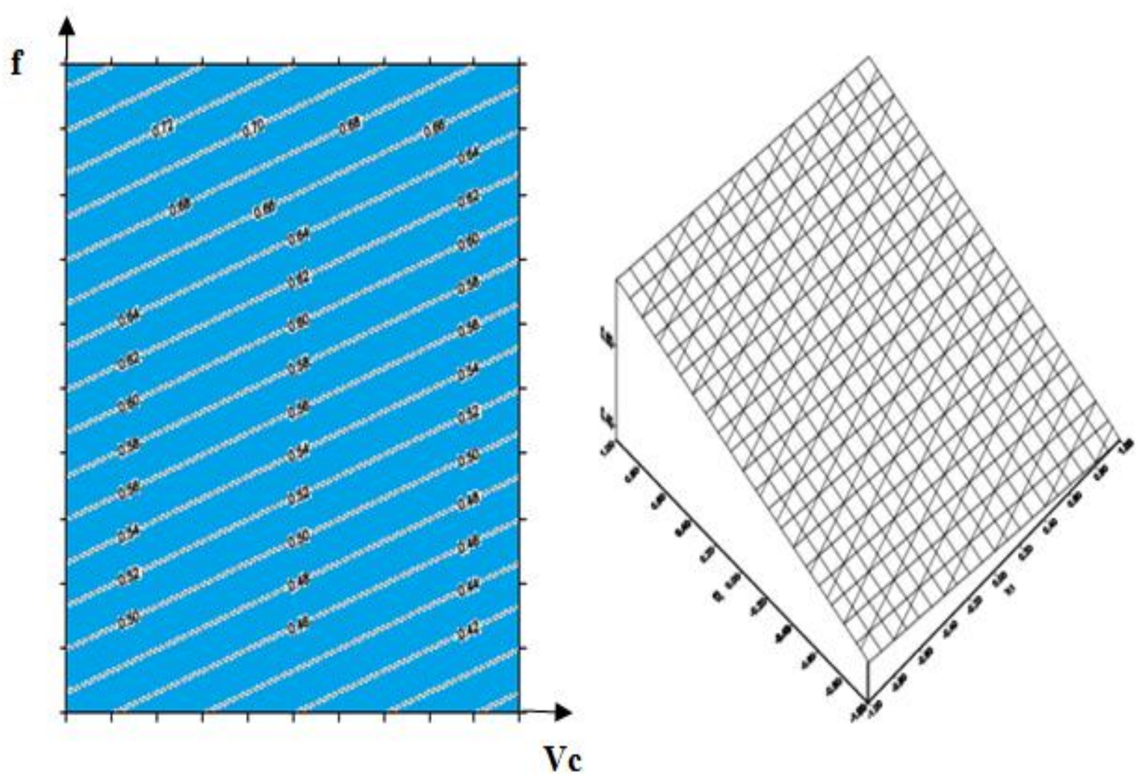


Fig. 5 Evolution of the roughness of the first material function of the cutting speed and feed rate

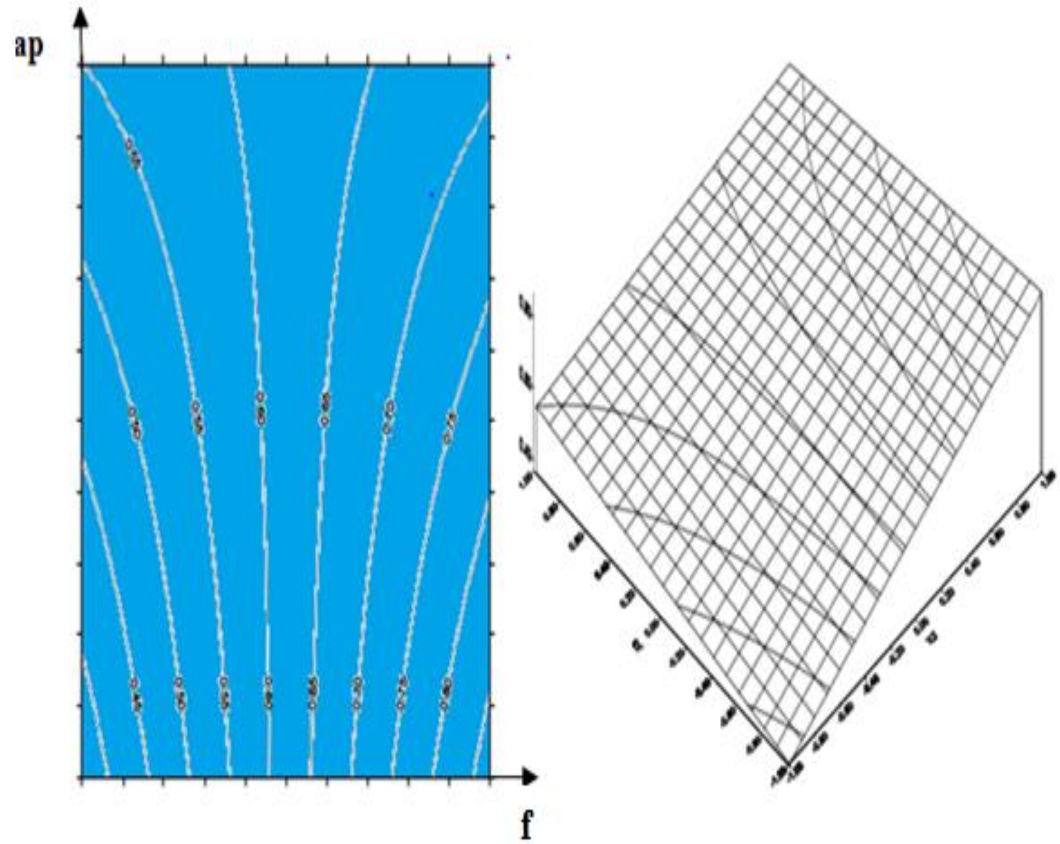


Fig.6 Evolution of the roughness of the second material function of the feed rate and depth of cut

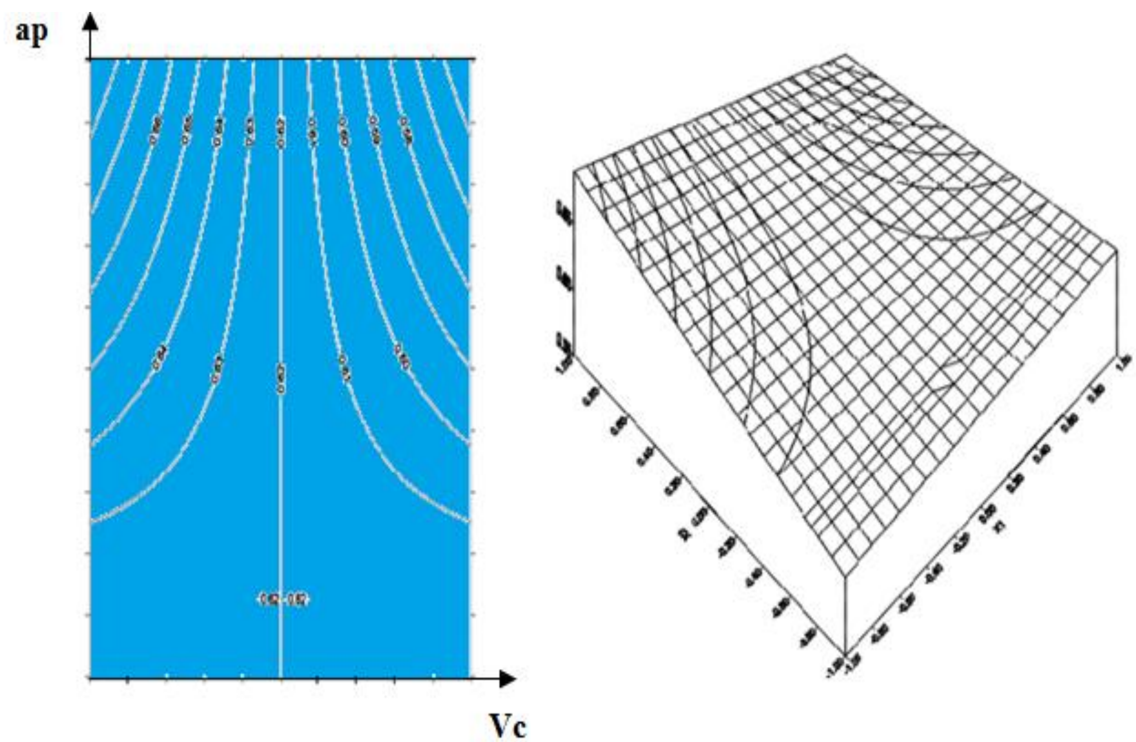


Fig.7 Evolution of the roughness of the second material function of the cutting speed and depth of cut

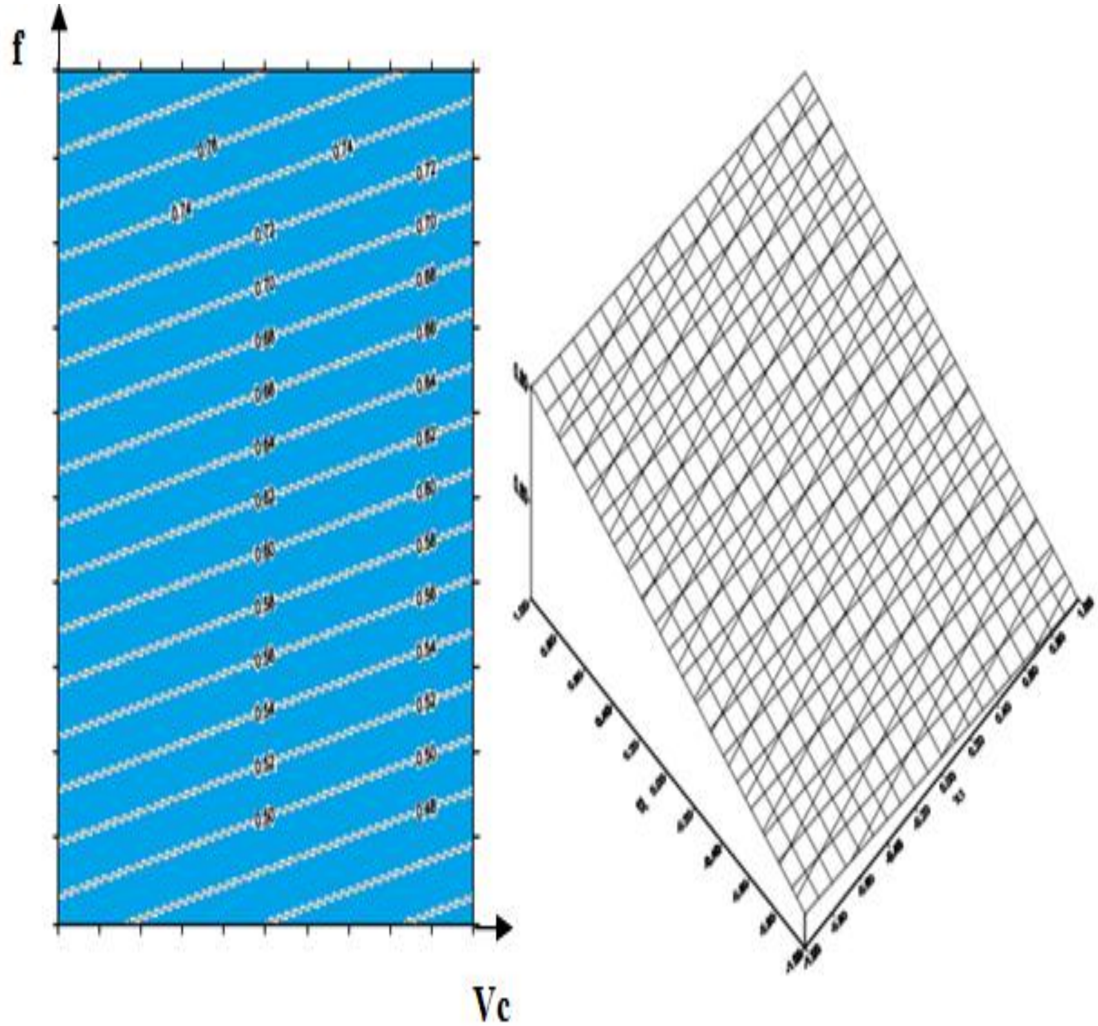
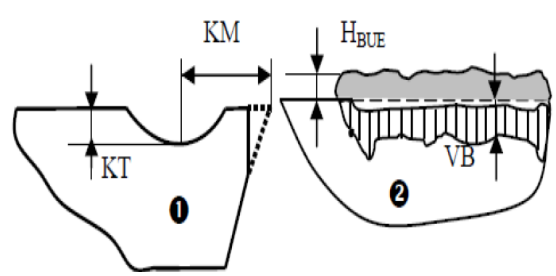


Fig. 8 Evolution of the roughness of the second material function of the cutting speed and feed rate

V. DEGRADATION OF TOOLS

The manifestation of the wear of the cutting tools and its assessment criteria are linked to measurable quantities called KT, KM, VB, HBUE and VKT, introduced in this analysis to better assess the evolution of wear of the tool, see Fig.4. These quantities are determined from binocular magnifying glass macrographies or surface topographies by confocal wide area roughness meter also called "optical roughness meter".

In our work, it should only be noted that this type of roughness meter uses so-called optical probes which have the advantage of making measurements without direct contact with the sample to be measured. Measuring these parameters makes it possible to monitor and determine, in certain cases, the optimal machining conditions[13].



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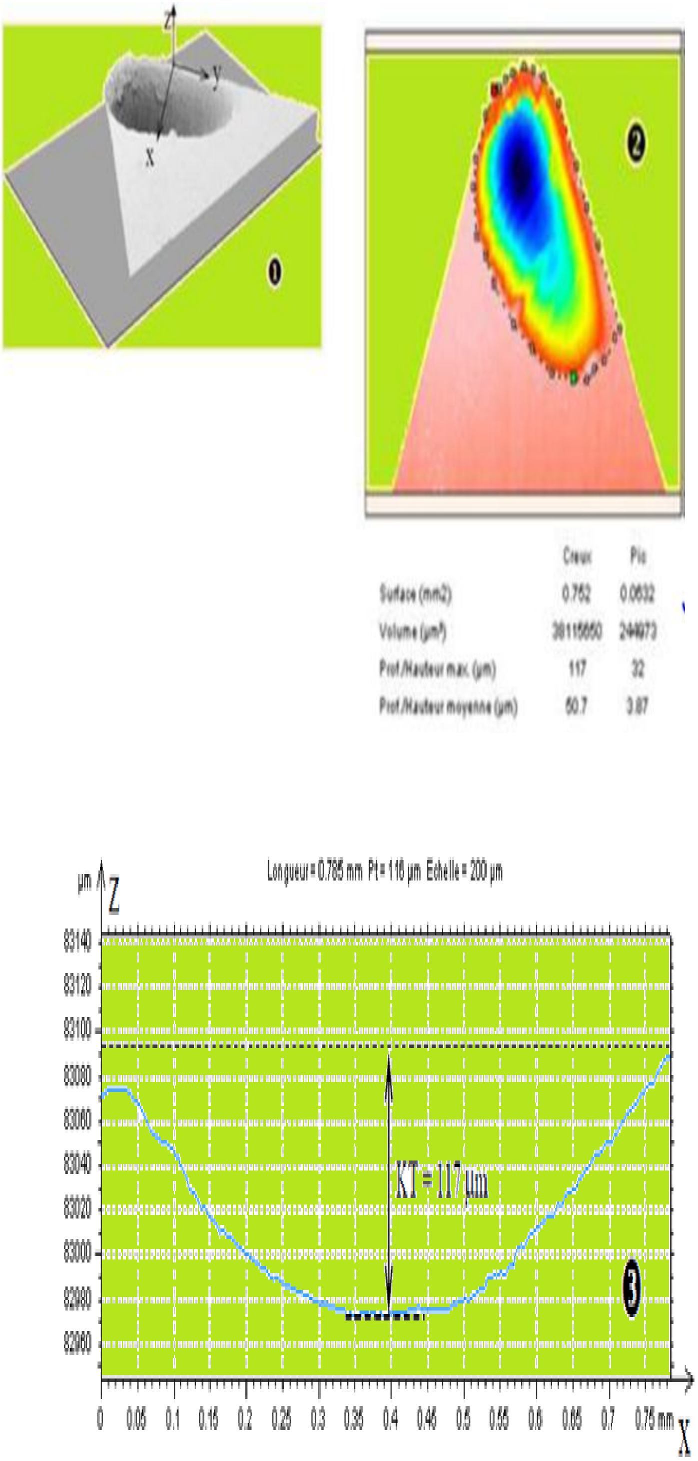

	Creux	Pic
Surface (mm2)	0.752	0.0632
Volume (µm³)	38115650	244973
Prof./Hauteur max. (µm)	117	32
Prof./Hauteur moyenne (µm)	50.7	3.87

Fig. 9 Crater topography 3D (Vc = 500 m/min, f = 0,1 mm/tr and ap = 1,1 mm)

In all the results which relate more specifically to the quantification of platelet wear, a feed speed f = 0.1 mm / rev, a cutting depth ap = 1.1 mm and a cutting speed between 150 and 500 m / min are considered. This choice is guided by the fact that the cutting speed is one of the most influential parameters on efforts, as shown by the results of other authors. Of plus, regardless of the cutting speed, the distance from the slip is the same for all tests.

CONCLUSIONS

Curves drawn by surfing show that only the cutting speed and feed speed have a significant impact on the roughness against by the depth of cut has almost no effect, as can be seen on Fig. 4, as well as on the global mathematical model to Eqs. (1) - (2), the two formulas do not contain the variable depth of cut, this will explain the no effect of depth of cut on the surface state, we can say as a synthesis

that:

The average roughness obtained by hard turning for both machined materials remains below to1 micron, which supports our bibliographic search.

Interpretation, of Fig.5 shows that the surface roughness decreases linearly with the cutting speed and feed rate, while the Fig.4, shows that the surface roughness decreases with increasing cutting speed without any influence of the depth of cut.

The shape of the curve Fig. 7, shows that for a cutting speed equal to 200 m / min roughness remains constant and equal to 0.62 micron for all depths tested passing, we also note that the roughness always remains constant and equal to 0.62 micron for values password included between 0.05 and 0.14 mm

The results obtained in the above Figures converge with the behavior of the physical phenomenon of metal cutting. The roughness decreases with increasing cutting speed and decreases with the decrease of the speed of advance.

When considering a confidence interval of 90% to draw the graphs of the evolution of the roughness, the depth of cut has virtually no influence on the evolution of the roughness.

The roughness seems to be a decreasing function of the cutting speed; the results also indicate that this roughness is an increasing function of the feed rate.

Analysis of the results also shows as well that the value of the roughness obtained by hard turning is comparable to that obtained by grinding, except that the machining is done on the same machine which influences wisely machining cycle.

Low cutting speed causes a tearing of material, it creates deep grooves, so a poor surface, just avoid cutting speeds important because the machining system becomes unstable and causes degradation of the surface of the work piece.

From the perspective of the economy dry machining is no coolant is used and therefore no waste must be eliminated.

REFERENCES

[1] M. BOURDIM (2012) Contribution à l'étude de l'intégrité de l'état de surface usinée en tournage dur, thèse de doctorat, ENSET d'Oran.

[2] M. REMADNA (2001) Le Comportement du système usinant en tournage dur : application au cas d'un acier trempé usiné avec des plaquettes CBN (Nitrure de Bore Cubique),Thèse de Doctorat, Institut National des Sciences Appliquées de Lyon.

[3] F.THIEBAUT (1995) Etude de la coupe à grande vitesse des aciers, mémoire de recherche bibliographique, DEA de production Automatisée, LUPRA ENS de Cachan .

[4] Y. MATSUMOTO et ALL(1999) Surface integrity generated by precision in hard turning, Annals of the CIRP, Vol. 48 No.1, 59-62.

[5] M. BOURDIM (2007) Usiner en tournage dur, 9ième Congrès de Mécanique Marrakech Maroc.

[6] M. BOURDIM (2009) FAO et Usinage à grande vitesse, 10ième Congrès de Mécanique Oujda Maroc.

[7] C.C. I KE, C.U. NWOJI, B.O. MAMA, H.N. ONAH, M.E. ONYIA (2019) Laplace

[8] Transform Method for the Elastic Buckling Analysis of Moderately Thick Beams. In- ternational Journal of Engineering Research and Technology 12 (10) 1626–1638.

[9] SANDVIK COROMANT (2005) Passez au tournage dur, Suède.

[10] TRAMETAL (2007) .Usinage à grande vitesse : Développements de nouveaux outils, Vol. 10 No.1, 7-15.

[11] K. M URAWSKI (2018) "Technical Stability of Continuously Loaded Thin-walled Slen- der Columns.". Lulu Press, Inc.

[12] T. KURITA, K. CHIKAMORI, S. KUBOTA and M. HATTORI (2006), A study of three-dimensional shape machining with an ECμM system," International Journal of Machine Tools and Manufacture, vol. 46, no. 12-13, pp. 1311- 1318.

[13] S. e. a. CHOI (2007), "Fabrication of WC microshaft by using electrochemical etching," The International Journal of Advanced Manufacturing Technology, vol. 31, no. 7, pp. 682-687.

[14] M. BOURDIM (2018), International conference on materials and renewable energy, University center of Relizane Algeria.