Determination of a wear law for uncoated cutting tools

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Abstract— The wear of cutting tools is one of the main current problems, especially when it comes to new materials called "difficult to machine" or with high added value. Tool wear is caused by extreme thermomechanical loads applied to the contact areas of tool chips and tool parts. During milling, turning or drilling operations, for example, large deformations, high deformation rates and high temperatures can be observed near the surface of the cutting tool. The objective of our work is to respond to the problem of abrasion wear by developing a predictive tool, based on knowledge of the physical and tribological mechanisms of workpiece-tool contacts, allowing us to quantitatively estimate the wear of the tool and its service life. To achieve this, we base our approach on previous studies carried out in the field of machining and metalworking. The modeling work was first applied to the wear case, then extended to the study of the crater wear occurring on the cutting face. By taking into account the mechanical load applied and the geometry of the contacts involved (plane-plane contacts), we have developed a two-dimensional approach in orthogonal cut configuration.

Keywords— ***Wear, thermomechanical, cutting speed, ships, tools, Damage, temperature, conditions.***

I. INTRODUCTION

There are several modes of wear which can occur simultaneously, mechanical wear (abrasion and adhesion), thermomechanical wear (fatigue), thermochemical wear (diffusion), electrochemical wear (oxidation). The increase in Cutting speed results in a decrease in adhesion wear, while all other types of wear increase. Kato and Adachi [1] have summarized the interrelationships of certain terms of usury depending on the type of contact, the state of deformation and the principles of material removal. According to Childs et al. [47], the degradation of cutting tools can be classified into two groups according to the scale of the study and the way in which the damage progresses: (i) - wear and (ii) - breakage at Fig (1). Grzesik [2] defined wear as a continuous phenomenon manifested by a loss of mass on the microscopic scale as is the case for diffusion, and / or on the scale of roughness or micro-switches.

On the other hand, and always according to Grzesik [48], the rupture of the cutting tools is a brutal damage and observable on a macroscopic scale. As illustrated on Fig (1), the wear of the cutting tools occurs mainly on: - the cutting face of the tool where there is the formation of a crater Fig (1 a) and / or an added edge Fig (1c); - the draft face Fig (1b), close to the cutting edge and beak radius; these forms of degradation are the direct consequence of the interactions between the tool, the machined material, and the chip under the effect of high pressures, high temperatures and high sliding speed. They depend on the nature of the contact (sticky, sliding or transient), the materials of the part and the tool as well as the cutting conditions.

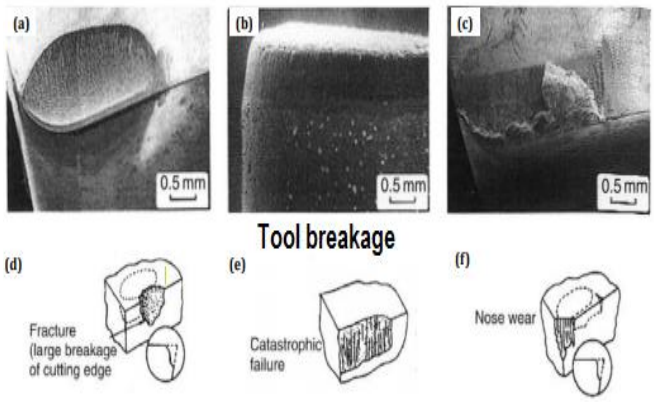

Fig.1. Damage due to wear (a-b-c) and breakage (d-e-f) of a cutting tool according.
(a) wear on the crater (b) wear on the printout (c) bonding and (d) edge chipping (e) sudden break (f) breakage of the tool tip. [3]

II. USURY LAW

The Taylor model [4] Eq. (1) is the most widely used empirical model in industrial applications (ISO 3685 for turning and ISO 8688 for milling). It can predict the life of the tool according to different cutting parameters once the coefficients n and C have been determined (constant parameters of the worn material and dependent on the tool / material pair respectively). However, it cannot show an actual amount of wear (used volume) during a defined cutting.

$$T = CV^{n} \qquad (1)$$

Takeyama and Murata [5] have suggested that overall tool wear can be described as a combined result of mechanically and thermally activated mechanisms on the surface of the tool. These authors concluded that the abrasive wear mechanism is independent of temperature and that its quantity is only proportional to the sliding distance, while the rate of physico-chemical wear depends largely on the temperature of the interface. They then formulated the total wear rate of the tool due to the combined effects of abrasion and physicochemical mechanisms as follows:

$$\frac{dW}{dt} = AV_S + B\exp\left(\frac{-E}{RT_{\text{int}}}\right) \qquad (2)$$

Where Vs is the sliding speed, Tint the temperature of the interface of the tool and E the energy of activation of the atoms which diffuse. A and B are the constants of the model and R the constant of ideal gases. Pálmai [6] suggested that the wear behavior of uncoated cemented carbide tools should be estimated more precisely taking into account the effect of the cutting length for mechanically induced and thermally activated wear processes:

$$\frac{dW}{dt} = AV_S + BV_S \exp\left(\frac{-E}{RT_{\text{int}}}\right) \qquad (3)$$

The constants A and B indirectly reflect the effects of the hardness of the tool material as well as the contact pressure on the overall wear rate. Usui et al. [7] extended the wear model adhesive to include the effects of contact pressure, sliding speed and interface temperature on the wear rate of the tool:

$$\frac{dW}{dt} = A\sigma_n \nu_S \exp\left(-\frac{B}{T_{\text{int}}}\right) \qquad (4)$$

The authors then concluded that this model can simulate the wear behavior of uncoated cemented carbide tools in different temperature ranges. Machining experiments were carried out on sintered steel bars containing aluminum oxide particles. The comparison results indicate that the proposed model can well represent the effects of abrasion using appropriate sets of parameters A and B in Eq. (4), [7]. This model was then used by several authors [75–81] to simulate the wear of coated and uncoated tools in the machining of steels, Ti-6Al-4V and superalloys based on Nickel “Ni” in a wide range range of cutting conditions. Eq. (5), can be further simplified by neglecting the effects of contact pressure on the overall wear rate, assuming that the contact pressure on the undercut wear surface remains constant with the evolution of wea:

$$\frac{dW}{dt} = A\nu_S \exp\left(-\frac{B}{T_{\text{int}}}\right) \qquad (5)$$

This hypothesis has been justified in certain experimental studies [8–9] which have shown that the cutting and feed forces increase linearly with the width of the wear zone.

III. EXPERIMENTAL STUDY

The means and techniques used to carry out our experimental study of the wear of cutting tools as well as the materials used are presented. The investigations were carried out in the case of the orthogonal cut. Mechanical characterization for hardness tests and physico-chemical analyzes is carried out on the study materials (tool and part).

A. . MODEL EXPERIMENTAL

The experimental study of the orthogonal cut was carried out on 42 Cr Mo 4 steel of chemical composition given at Table 1. The latter is one of the structural steels low in alloy with chromium and molybdenum. This grade of steel belongs to the category of hardened quenched steels.

First, a spectrometric analysis was carried out on this material. It allows us to check the chemical composition. This analysis is carried out using a spark spectrometer, on a sample of "crude" steel in which the test pieces have been machined, see Table1.

Table 1. Chemical composition of the test piece

% By Masse	% C	%Cr	%Mo	%S	%Mn	%Si	%Al
	0,47	1,05	0,21	0,02	0,71	0,29	0,04

The cutting speeds and feed speeds used are as follows see Table 2.

Table 2. Chemical composition of the test piece

V (m/s)	0,84	1,35	1,67	2,5	3,33	4,2	4,75	5
f (mm)	0,04	0,16	0,18	0,2	0,25	4	-	-

The cutting tool in Fig (2), is made up of an irreversible triangular plate of titanium carbide coated of type TNMG 16 04 08 and of a tool holder for designation SOGIMO 90° 20W3K10 with the following geometry:

φ = 95°; α = 6° and = -6°.

Fig. 2. Tool used

The machining was carried out without lubrication on a conventional parallel lathe of brand "TOS TRENCIN" Fig (3). With a power of 6,8Kw of the technological hall of the university Abou Bekr Belkaid of Tlemcen.

Fig. 3 general view of machining

The purpose of the tests is to study and identify the wear which appears at the level of the tool's contact interfaces with the part (tool / chip contacts and tool / freshly machined part). The tests were carried out in two series. The first made it possible to determine the so-called stable cutting conditions; it is based on a COM study "Material Tool Couple" defined by standard NF E66-520. The second series has as its main objective the study of wear and the influence of cutting parameters on the degradation phenomenon.

Note that the choice of f for this study follows a preliminary test where 2 cutting speeds and 3 feeds were adopted and an analysis of the wear and tear was carried out. This study revealed that the wear was less pronounced for an advance of f = 0.12 mm and in the case where Vc = 1.67 m / s. The parametric study of V will first determine a minimum cutting speed Vmin which will be used for the parametric study of the influence of the feed f. Secondly, a range of cutting speeds will be identified in order to define the second series of tests, namely the wear tests.

IV. Results and Discussions

Fig (4), shows that wear becomes significant from high cutting speed V> 3.35 m / s. Furthermore, the wear force is more pronounced on the feed force Fa and on the specific feed force Ka where a change in speed from 4.2 to 5 m / s induces an increase in 73% on Ka, which represents relatively rapid growth.

The appearance of wear on the draft face as well as on the cutting face for the preliminary tests of the COM are illustrated in Fig. 4. The latter gives the evolution of VB and KT parameters as a function of the cutting speed for a feed f = 0,15 mm. The quantity of material machined is the same for all points.

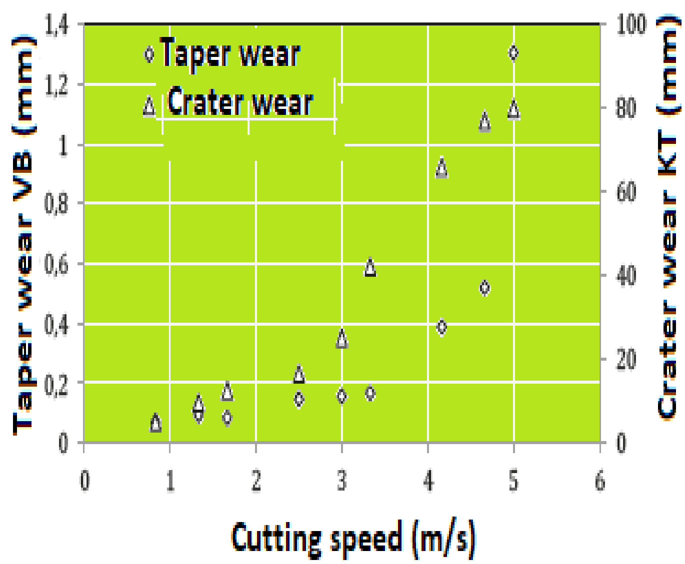

Fig. 4. Evolution of the undercut wear VB and the crater wear KT as a function of the cutting speed V for f = 0.15mm

Fig (5), illustrates the variation of the machining forces Fc and Fa and that of the specific cutting and feed forces (kc) and (ka) as a function of the feed f. In Fig (5a) we see the common quasi-linear increase for the cutting and feed forces with the feed f due to the increase in the cut section (f. w).

Nevertheless, the slopes of the force curves are more significant for cutting forces than for advancing forces. A variation from 0.04 to 0.4 mm induces a variation of 71% for cutting forces and 33% for advancing forces.

It also appears from Fig (5b), that the effect of the edge radius rβ is perceptible at low advances where the ratio Fc / Fa is close to 90% for f = 0.04 mm. Indeed, the appearance of an indentation effect results in a new effort component which is added to the advance effort Fa [19, 20].

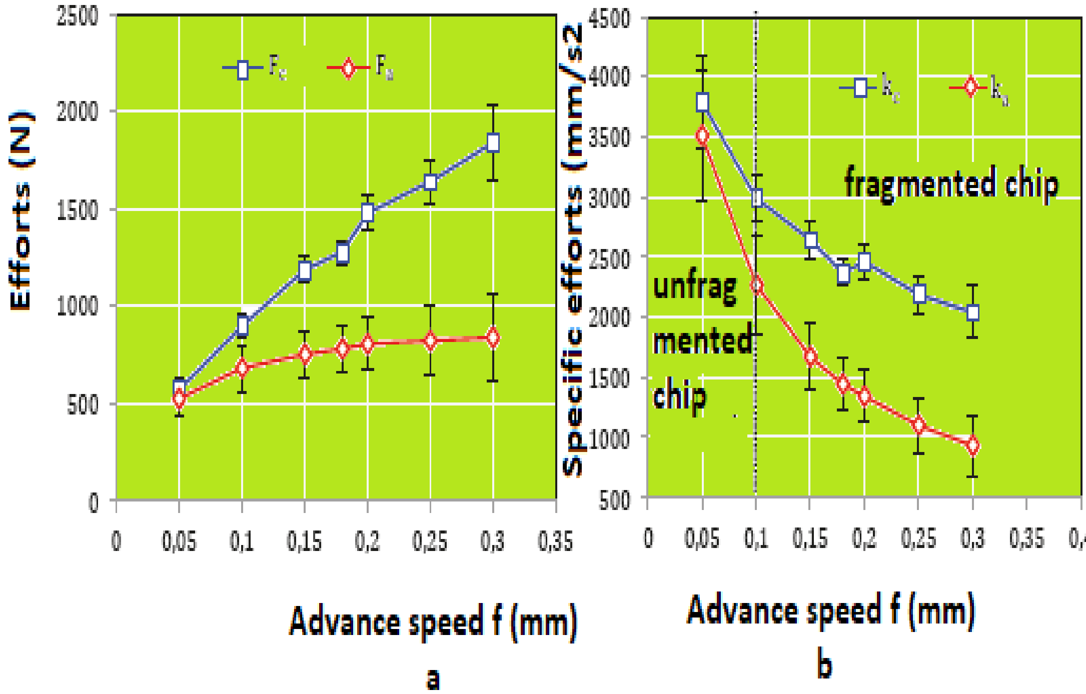

Fig.5. (a) Evolution of the forces and (b) specific cutting and feed forces as a function of the feed f.

The appearance of the chips is an important criterion that determines the choice of the advance range. Fragmented chips are easy to remove and continuous chips can wrap around the tool or on itself, which increases wear and tear on the cutting tools. Consequently, a fragmented chip indicates ideal cutting conditions which, unlike the evolution of wear as a function of speed, this one not have any significant influence on the speed of advance as illustrated in Fig (6).

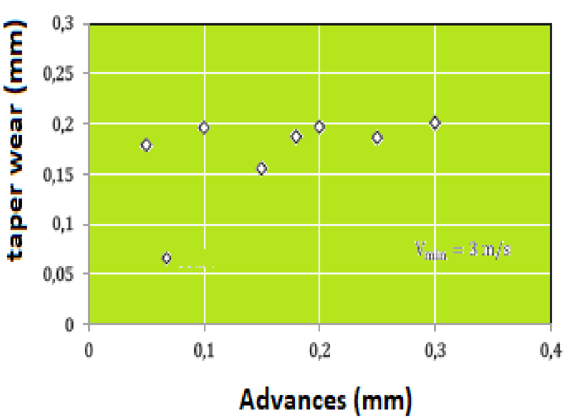

Fig.6. Effect of advance f on wear and tear VB and for Vmin = 3 m / s.

Fig (7) illustrates the evolution of VB as a function of the machining time for different cutting speeds. It clearly shows that the evolution of VB is faster for high cutting speeds.

For example, for the case of V = 1,67m / s and f = 0,25 mm the maximum measured value of VB is approximately 0,15 mm after a period of 18s. This value of VB is almost equivalent to that obtained for the cutting speed 4,17 of m / s after only 2,5 s of cutting. But it should be noted that the cutting speed 1,17 m / s is not part of the "stable" cutting conditions determined from the results of the COM. This cutting speed nevertheless makes it possible to consider longer cutting times before the ultimate degradation of the insert. Finally, the speeds 2,5 and 3 m / s considered as “stable” cutting speeds cutting speeds present a similar evolution with a VB growth slower for 2,5 m / s than for 3 m / s.

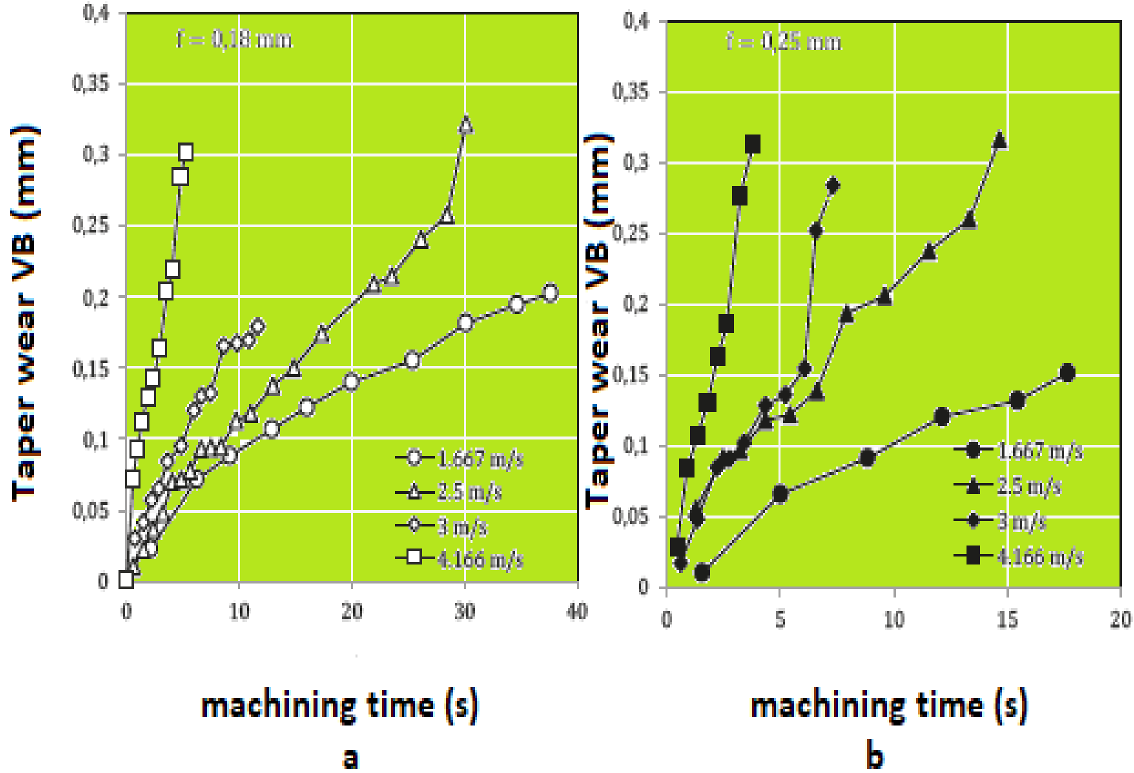

Fig.7. Evolution of wear in clearance VB as a function of time for different cutting speeds V (a) f = 0,18 mm (b) f = 0,25 mm

The Fig (8) clearly shows that the cutting speed is the most influential parameter on wear. The width and position of the crater decrease with the cutting speed. The rate of evolution of the depth of the crater, meanwhile, increases with the cutting speed.

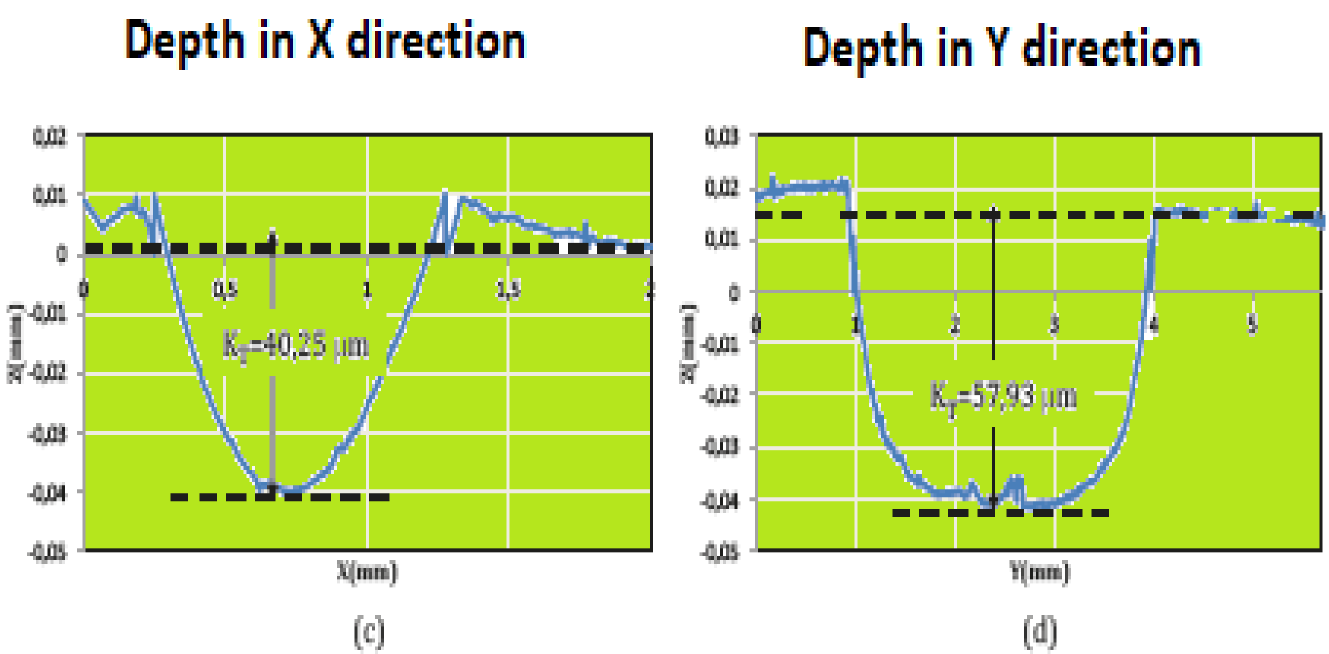

Fig.8. Topography of crater wear. V = 1.68 m/s f = 0.18mm

V. CONCLUSIONS

The objective is to analyze the wear of uncoated tungsten carbide cutting tools when cutting 42CrMo4 steel. In this context, a certain number of machining tests have been carried out accompanied by experimental measurements to demonstrate the dependence of the wear phenomena on the cutting conditions and the cutting forces generated during the machining process.

Finally, the wear analysis carried out shows that the craterisation of the cutting face is due to diffusion wear for high cutting speeds (with a slight contribution from the other abrasion and adhesion wear modes). For low cutting speeds (V < 3 m / s), the characterization is mainly due to abrasion wear. This is how we became interested in the appearance of a crater on the cutting face.

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