Archives of Materials Science and Engineering

Volume 114
Issue 1
March 2022
Pages 5-12

International Scientific Journal
published monthly by the
World Academy of Materials
and Manufacturing Engineering

DOI: 10.5604/01.3001.0015.7023

Experimental study of the wear behaviour of a metal carbide tool in turning by dimensionless analysis

F.D. Amier [a],*, F. Belarifi [b],*, R. Noureddine [a]
[a] E.N.P.O. - National Polytechnic School of Oran, Oran, Algeria
[b] L.S.M.C. - Tribology and Nano-tribology Team, Department of Physics,
Oran University, Oran, Algeria
* Corresponding e-mail address: amier.fouad@gmail.com (F.D.A.); belarifi_farid@yahoo.fr (F.B.)
ORCID identifier: https://orcid.org/0000-0002-8550-2098 (F.B.)

ABSTRACT

Purpose: In this article, we present the experimental results with a dimensionless analysis of the wear behavior of a metal carbide tool in a turning operation.

Design/methodology/approach: The highlighting of the dimensional input and output parameters of the experimental tests to bring out the different adimensional parameters. Regarding the input parameters, we have the rotational velocity (N), the feed (f), the depth of cut (ap), the machining time (t). The output parameters are defined by the flow rate (DC), the volume of the used tip (VU), the face wear (VB), as well as the cutting power (PC) and that of the machine (PM).

Findings: The dimensionless approach allowed us to find the desired cutting conditions as well as the possibility of working in ranges of cutting conditions for known wear, which is not possible with a dimensional analysis. It should be noted that the appropriate choice of these parameters was essential to achieve these results.

Research limitations/implications: The existence of a working range proposed by this analysis leads us to the proposal of a model and a numerical optimization.

Practical implications: This work offers the desired compromise of adequate cutting conditions during machining.

Originality/value: Deduction of adequate cutting conditions with minimum wear. Among other things, we can extrapolate the results to offer us compromises in the choice of ranges of cutting conditions.

Keywords: Wear, Turning, Metal carbides, Cutting tools, Dimensionless analysis

Reference to this paper should be given in the following way:

F.D. Amier, F. Belarifi, R. Noureddine, Experimental study of the wear behaviour of a metal carbide tool in turning by dimensionless analysis, Archives of Materials Science and Engineering 114/1 (2022) 5-12. DOI: https://doi.org/10.5604/01.3001.0015.7023

PROPERTIES

1. Introduction

Wear, in general, is a complex phenomenon and has been the subject of a certain number of studies synthesized in the work of Diamandiev [1], M.C. Shaw [2] and Senhadji et al. [3]. As far as the wear of the cutting tool is concerned, it is governed by several mechanisms which are not yet perfectly mastered yet, nor fully identified. This is the photography of the cumulative effects of all damage to the active tool edge during a well-defined machining operation, as shown by Cheleon et al [4]. The state of the art of tool wear is distinguished by a multitude of works, whether experimental, theoretical or simulation. With regard to experimental work, we note those of Marinov [5], Xie, et al. [6], Molinari et al. [7,8], Khrais et al. [9], Boujelbene et al. [10], Ferdinandov et al. [11], Dobrzanski et al. [12], as well as the work of Amier [13] who dealt with the wear of metal carbide tools. As for the theory of wear, it was treated by the works of Dudzinski et al. [14], Li [15], Filice [16] Salvatore [17], Lyashenko et al. [18], Delijaicov et al. [19].

The development of digital tools as well as high-performance software have concretized the simulation of the wear of cutting tools by finite elements, of which we can cite the work of Chang et al. [20], Afrasiabi et al. [21-23] and those of Gedidech [24]. We notice in the analysis of the state of the art of tool wear, the multitude of results, but industrial evolution always requires, more in terms of understanding, the machining of specific materials.

In this context, we propose in this article an experimental study of the wear of a metal carbide cutting tool of grade P30 with an adimensional analysis of the results [25], in a turning operation in order to find better cutting conditions guaranteeing machining at economical conditions or with less wear. Indeed, we have noticed from the various studies having dealt with tool wear [13,24], that is generally conditioned by the cutting velocity, the machining time, the feed and the depth of cut.

These parameters are found in most of the dimensional models combined or separately [18]. On the other hand, the dimensionless aspect has not been treated or very rarely in these studies. It should be noted that this analysis is based on the observation of the input and output parameters, which represents a description of any physical phenomenon, but the difficulty in dimensionless parameterization is to find the representative parameters. In our case, we end up with four parameters a dimensioned according to the cutting speed, the feed rate, the depth of cut, the machining time as well as the cutting power and that of the machine. The dimensionless approach proposed allowed us to find the possibility of working on ranges of cutting conditions for known wear, which is not possible with a dimensional analysis. We point out, that the adequate choice of these parameters was essential to arrive at these results.

2. Experimental study

It consists in monitoring the flank wear of P30-type metal carbide inserts, stock removal operations according to the various cutting parameters (*Vc, ap, f*). The tests were carried out on a conventional parallel lathe, for a fixed time limited to two minutes. The different characteristics of the test are shown in Table 1, and the test campaigns are shown in Figure 1. The machining operation and the metal carbide insert, are shown in Figure 2.

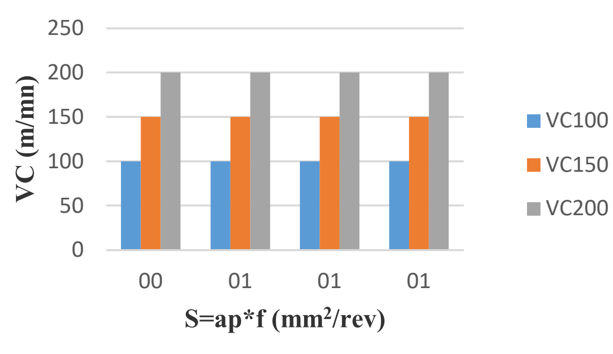


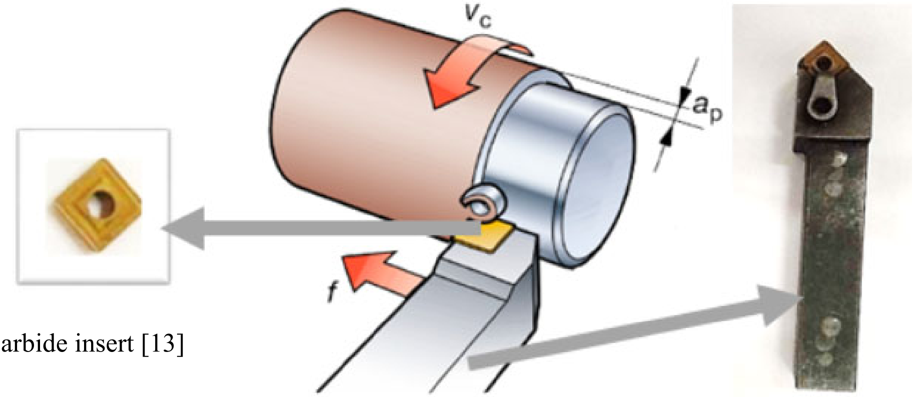
Fig. 1. Test protocol

3. Test results

The combination of the different cutting parameters allowed us to carry out a campaign of twelve tests, in which we changed the machining insert for each test and the adaptation of the cutting conditions according to the pre-established protocol, as indicated by Table 1.

Table 1.
Test characteristics

Workpiece	Tool	*VC*, m. mn^{-1}	*D*, mm	*f*, mm/rev	*ap*, mm	*t*, mn	*PM*, KW
42CrMo4	Carbide P30	100 ; 150 ; 200	70	0.2 ; 0.3	2; 4	2	14



Metal carbide insert [13]

Platelet holder [13]

Fig. 2. Turning operation

This allowed us to measure for each test the value of the wear of the insert (*VB*) and the flow rate or the volume of the chip produced ($DC = \frac{m}{\rho}$) for each experiment.

It should be noted that the front wear (*VB*) of the platelets has been analyzed and measured under a metallographic microscope (Fig. 3) with an accuracy of 0.01mm and a magnification of 200 times.

Fig. 3. Photo of ZWICK microscope

3.1. Metallographic analysis

Photos *a, b, c, d, e* and *f* (Fig. 4), represent the overall behavior of the tools for cutting speeds of 100 mmn^{-1}, 150 mmn^{-1} and 200 mmn^{-1}, for different feeds and depths of cuts.

Observations of photos *a* and *b*, obtained for *VC100*, showed uniform surface wear varying in the order of 0.05 mm to 0.6 mm. For photos *c* and *d*, obtained for *VC150*, observations show wear which increases in depth and that it varies from 0.13 mm to 1.5 mm. We notice a trend towards degradation of the cutting edge.

Regarding the photos *e* and *f*, which represent the results for *VC200*, we notice an accelerated degradation of the nose of the tool with values of wear between 0.3 to 2.1 mm, whatever the values of *f* and *ap* with which *VC* is associated.

We noticed rapid tool wear long before we finished programmed machining and even breakage of the tool's cutting edge.

3.2. Dimensionless analysis of tests

The analysis of the various results shows us that the representation concerning the worn volume of the edge and the flow rate are not representative in the same figure, because the ratio of the flow rate of the chips is greater by 26 to 5000 times than the worn volume. It is for this reason that a dimensional representation becomes difficult to interpret and we have opted for a dimensionless representation which highlights the different parameters of the experimental tests.

Choice of parameters

The parameters highlighted in this analysis are the input parameters namely, the rotation velocity (*N*), the feed (*f*), the depth of cut (*ap*), the machining time (*t*) and of output namely flow (*DC*) worn nozzle volume (*VU*) and front wear (*VB*). Our observations brought out four dimensionless parameters.

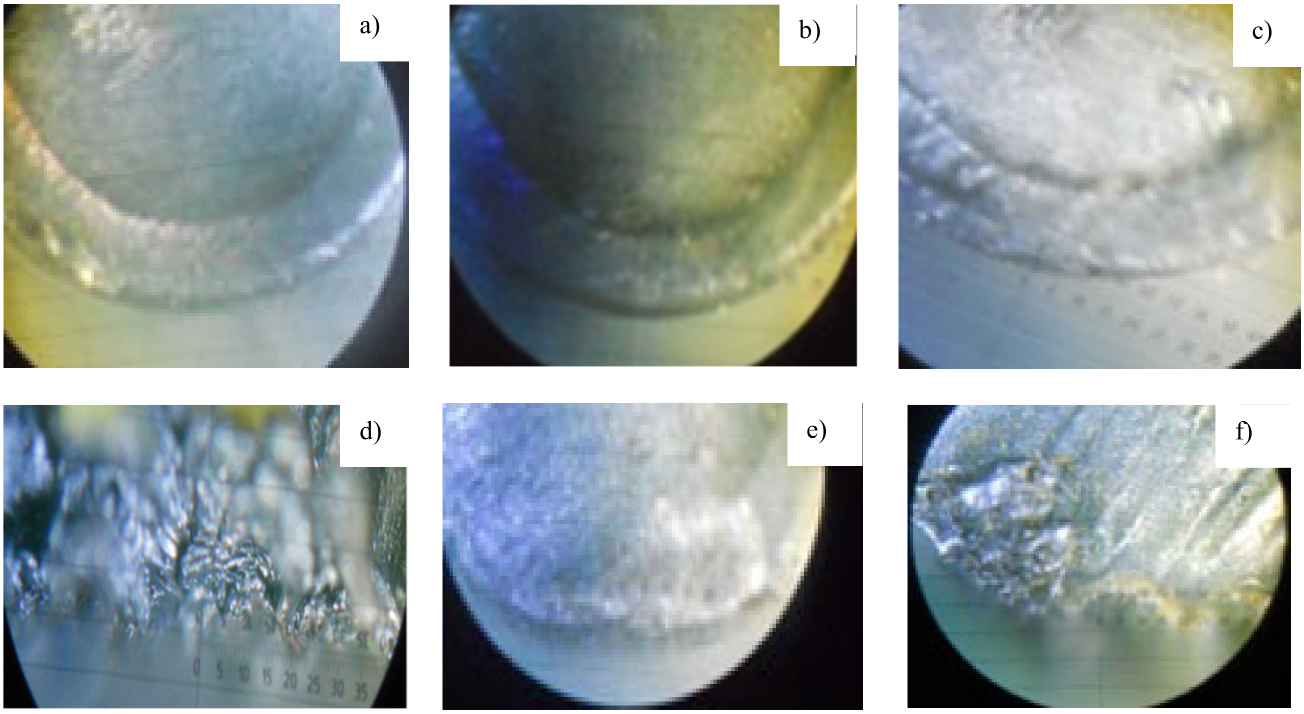


Fig. 4. Photos of metallographic analysis: a) VC100, ap2, f0.2; b) VC100, ap4, f0.2; c) VC150, ap2, f0.2; d) VC150, ap4, f0.3; e) VC200, ap2, f0.2; f) Vc200, ap2, f0.3

The cutting conditions parameter ($\overline{AB}$), which represents the machined length (*L*) over the depth of cut (*ap*), is written:

$$\overline{AB} = \frac{L}{ap} \tag{1a}$$

with:
the machining length is written:

$$L = f^{*}N^{*}t \tag{1b}$$

and, the velocity of rotation is written:

$$N = \frac{10^3.VC}{\pi.D} \tag{1c}$$

$$\overline{AB} = \frac{f^{*}N^{*}t}{ap} \tag{1d}$$

The wear parameter associated with the cutting conditions ($\overline{VB}$), which represents the ratio of the value of the wear measured over the machined length, is written:

$$\overline{VB} = \frac{VB}{L} (2)$$

The volume parameter $\overline{U}$,represents the ratio between the worn volume of the cutting edge (*VU*) measured after each test, associated with the volume of the chip (*DC*) produced during the test, is written:

$$\overline{U} = \frac{VU}{DC} \tag{3}$$

The dimensionless power is written:

$$\overline{P} = \frac{PC}{PM} \tag{4a}$$

PM: represents the engine power of the machine, indicated in Table 1.

Cutting power is written:

$$PC = FC.VC \tag{4b}$$

with:

$$FC = Kc.S \tag{4c}$$

and:

$$S = ap.f \tag{4d}$$

Therefore, the power in Watt is written:

$$PC = Kc.S.VC \tag{4e}$$

For PC in Kilowatt (KW), the equation (4e) becomes:

$$PC = \frac{Kc.S.VC}{60.10^3} \tag{4f}$$

For our material (42CrMo4), *Kc* = 2100 Nmm^{-2} [26].

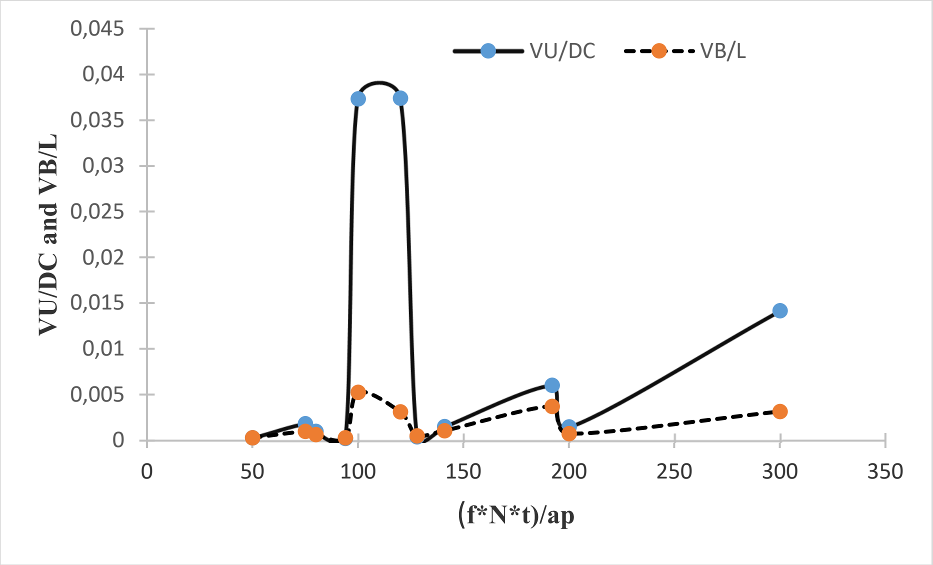


Fig. 5. Variation of wear and chip flow as a function of the $\overline{AB}$ parameter

Representation of results and discussions

The representation of the various results, were established according to the dimensionless length $\overline{AB}$ and the and the dimensionless power $\overline{P}$. We notice in this approach the possibility of a dimensionless representation of the wear and chip flow values on the same figure with different graphs and a good representative scale, as shown in Figure 5. This represents the dimensionless evolution of wear $\overline{VB} = f(\overline{AB})$ and volume $\overline{U} = f(\overline{AB})$.

The analysis of Figure 5, allows us to distinguish four distinct zones with parabolic shapes for the first three zones and increasing linearity for the last zone, with maximum values for $\overline{VB}$= 0.005, and $\overline{U}$= 0.04, lying in the zone $\overline{AB}$ between values 100 to 128. Regarding the values $\overline{AB}$ below 100, we have to do at low cutting speeds, because as it was noticed during the dimensional analysis, we have a weak influence of *ap* and *f* on the wear and chip flow.

For values of $\overline{AB}$ between 128 and 200, we have very close wear and volume which are of the order $\overline{VB}$= 0.003 and $\overline{U}$ = 0.0037 lying for $\overline{AB}$ = 192.

For values of $\overline{AB}$ between 200 and 300, we have a linear behavior with a value of $\overline{VB}$ = 0.031 and $\overline{U}$ = 0.0141 lying for $\overline{AB}$ = 300.

We notice from this analysis, that the second zone is predominant, giving the maximum production of the chip flow, but in return we also have a maximum wear, this is what we call the economic working zone, the first zone (50-100) is the area of least wear, but the cutting time will be longer, as the cutting speeds will be low.

Regarding zone three, this is the zone of equal wear and throughout, where optimal machining conditions are found, with high cutting speeds and correct machining times.

Zone four, seems very interesting to us if we manage to guarantee the best cutting conditions in the measure of being able to reduce or have a constant wear while increasing the chip flow which will be a rather difficult compromise to guarantee, but possible with the new carbide coatings [24].

With regard to Figure 6, the first observation is that the two curves have the same tendency, with values of $\overline{U}$ always higher than those of $\overline{VB}$ and that the two curves pass through three zones.

The first, the values are almost constant for values of $\overline{AB}$ between 0.2 to 0.4, then we have a turning point on the curve at $\overline{P}$ = 0.42, and an increase of the values in a parabolic way at the maximum point is located at $\overline{P}$= 0.47.

In the last zone we have an increase of the two curves so that $\overline{U}$ and $\overline{VB}$ reach their maximum values, at $\overline{P}$ = 0.83 and thereafter the curves begin their decreases.

Search for optimal cutting conditions

The search for the best conditions consists in finding the closest values between the $\overline{U}$ and $\overline{VB}$ curves (Fig. 5) and checking the dissipated power (Fig. 6).

In this context we notice two areas which appear as likely to meet our needs. An area for $\overline{AB}$ comprised between 50 and 100 and an area for $\overline{AB}$ comprised between 141 and 200, for these values the curves of Figure 6, gives us an area for $\overline{P}$ comprised between 0.2 to 0.6. The maximum values of these different zones are shown in Table 2.

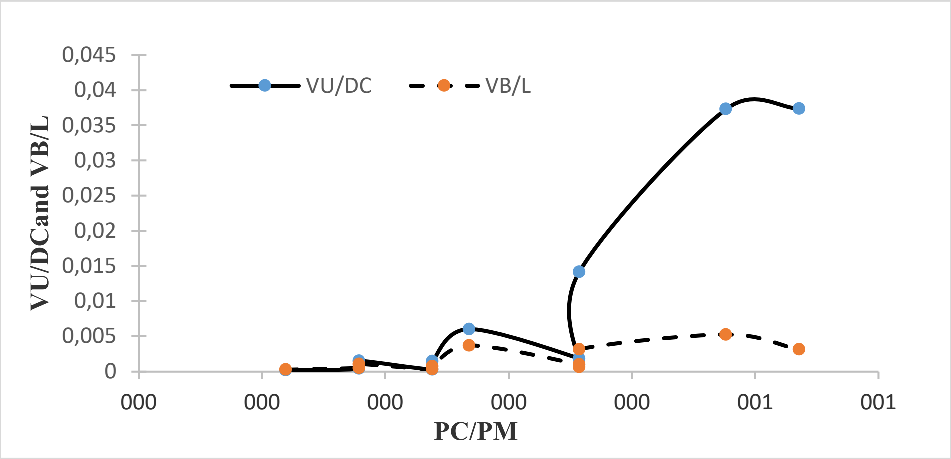


Fig. 6. Variation of wear and chip flow as a function of the power $\overline{P}$

Table 2.
Maximum values of the different curves

Dimensionless parameters				Cutting conditions			
$\overline{VB}$	$\overline{U}$	$\overline{AB}$	$\overline{P}$	*VC*, m.mn^{-1}	*f*, mm.rev^{-1}	*ap*, mm	*L*, mm
0.001	0.00182	75	0.31	100	0.3	2	282
						4	300
0.0037	0.006	192	0.47	150	0.3	2	384

We notice in the latter, that we have a combination of possibilities to achieve machining conditions with a minimum of wear and an adequate flow, in this context, we observe that the cutting speeds *VC100* and *VC150*, are the most suitable for our materials with a feed rate of *f0.3* and depth of cut *ap2* or *ap4*. We recommend that if we have to stick to an economical machining we must adopt the conditions of *VC150*, on the other hand for a machining with less wear we must adopt *VC100* with *ap2* or *ap4*.

4. Conclusions

During any machining, the choice of cutting conditions must meet a strategic need to work in economic conditions or with less wear. In the first case, we have accelerated wear and increased tooling change and minimal machining time. In the second case; we have increased machining time and decreased tooling change. In this context, we were interested in this study to determine the adequate cutting conditions of an experimental protocol of the machining of a stock removal operation by an dimensionless analysis. This analysis was developed on the basis of parameters highlighted during the experimental protocol, namely cutting speed, feed and depth of cut, to these parameters we added the stock removal length, the cutting power and that of the machine. Therefore, we have identified all the parameters of the cut.

The various results obtained show the following:

- deduction of adequate cutting conditions with minimum wear;
- wide choice in the cutting condition ranges, by setting *f* 0.3 with *ap* varying from 2 to 4 mm and *VC* varying from 100 to 150 mmn^{-1};

To complete this work and offer the desired compromise of adequate cutting conditions during machining with minimum wear and maximum chip flow, we have synthesized two axes. The first is a numerical optimization by dimensionless parameters. This work is already underway and will be the subject of a future publication. The second consists of an in-depth investigation for the high speed ranges from *VC200* where the premature wear of the carbide inserts requires particular attention in the judicious choice of the cutting conditions not yet determined or difficult to achieve.

Nomenclature

$\overline{AB}$	Dimensionless length	[--]
Ap	Depth of cut	[mm]
D	Gross part diameter	[mm]
DC	Chip flow	[cm^{3}]
F	Advance per revolution	[mm.rev^{-1}]
FC	Cutting force	[N]
Kc	Specific cutting pressure	[Nmm-^{2}]
Lo	Total length of the piece	[mm]
L	Turning length	[mm]
m	Weight	[Kg]
N	Workpiece rotation velocity	[trmn^{-1}]
$\overline{P}$	Dimensionless power	[--]
PC	Cutting power	[KW]
PM	Power of the machine	[KW]
$\overline{U}$	Dimensionless volume	[--]
$\overline{VB}$	Dimensionless wear	[--]
VB	Frontal wear of the tool	[mm]
VU	Worn volume	[cm^{3}]
S	Section of material removed	[mm^{2}]
t	Time	[mn]
ρ	Volumetric weight	[Kg.cm^{-3}]

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