Comparison Between the Evolution of the Wear Rate and the Temperature in the Cutting Area

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Abstract: For the complete study from a tribological point of view of the cutting process, very important is the heating phenomenon of each element participating in the process (chip, tool blade, workpiece), their temperature being in fact the factor with the greatest influences on the behavior of the chip – tool blade tribosystem. It was necessary to develop a physical model of the phenomenon in order to perform the researches; in fact, the phenomenon is a conventional image of the real status, representing the basics of mathematical modeling. Experimental research on tool blade temperature and wear intensity of cutting tool has established similarities between the evolutions of the two phenomena. Therefore, by modelling the evolution of the thermal phenomenon can be determined the evolution of the wear intensity by applying a proportionality constant, constant that can be determined experimentally and which remains the same for the same couple: the chip-cutting tool blade.

Between a size characteristic of tool tool wear, respectively the intensity of wear and the temperature in the cutting area, a dependency relationship was established which, with rather small deviations, is a dependency of direct proportionality; thus, from the measurement of the temperature in a tribosystem it is possible to evaluate, at least at cutting, the wear intensity of cutting tool.

Key-Words: - the wear intensity of cutting tool; cutting process; wear intensity

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1 Introduction

In the cutting process, the different types of wear rarely occur separately, they usually occur simultaneously, one type or another of wear having preponderance depending on the cutting conditions. These conditions are mainly the type of mating of the workpiece and tool material, the cutting speed and temperature, as shown schematically in the principled diagram in figure 1 [1], [2], [3], [4].

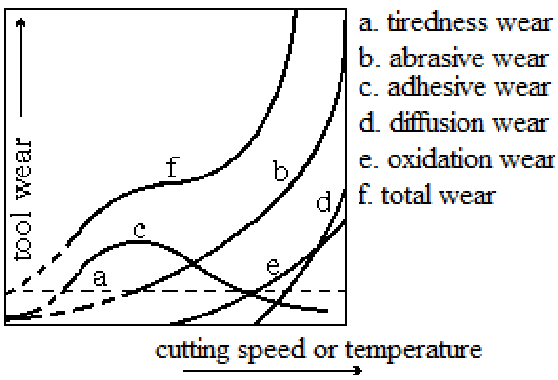

Figure 1. The influences of partial wear on total wear

On the front face of tool appears a crater measuring $a \times KB$ at distance f from the edge of the edge and depth KT . The value a is with very good approximation, equal to the width of the chip detached in the cutting process. The characteristic size of the crater is its depth, KT, and its evolution over time is relatively rapid in the first moments of cutting, after which it becomes almost constant (stabilizes). The wear of the front face is favorable to the cutting process, leading to an increase in the front face angle from the value γ to the value γ_i' contributing to the reduction of the cutting effort, to the more convenient direction of the chip, the more so as its characteristic size, KT, stabilizes.

The facet f has the role of vibration damping. A minor disadvantage may be mentioned, namely the reduction of the caloric capacity of the cutting edge, respectively the susceptibility of its excessive heating, but must also be taken into account the reduction of the energy load of the cutting edge due to the reduction of the cutting effort.

On the back edge of tool appears a wear facet on a edge length corresponding to the width of the chip and whose characteristic width is denoted by *VB*, fig.2.

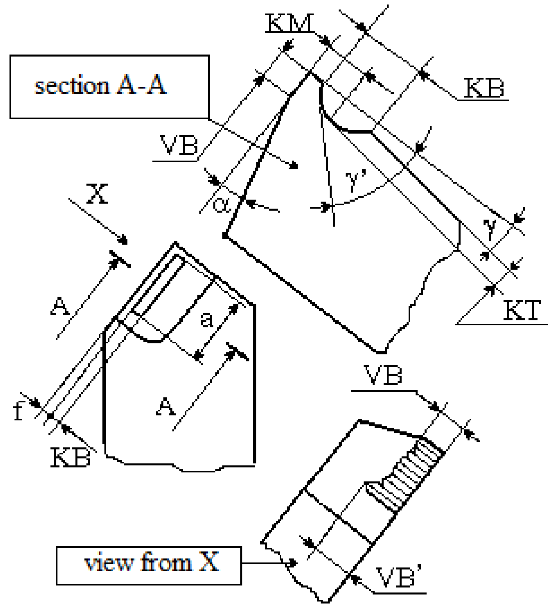

Figura 2 The wear of the edge of a cutting tool

On the wear facet, the back edge angle is null, an unfavorable value for the cutting process.

In operation, there are three distinct areas with different evolutions of the value of *VB* size, respectively a first area characterized by a rapid increase in the first moments of cutting, period in which the running-in wear occurs, followed by an area corresponding to a period in which the value *VB* size increases relatively slowly, called the period of wear regime after which there is a very rapid increase in *VB* size until the total loss of cutting capacity of the tool edge, during this period catastrophic wear occurs, fig. 3.

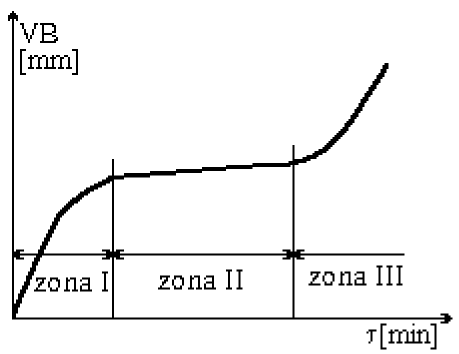

Figure 3 The evolution of wear over time

The wear of the front face, faster in the first moments of the cutting, stabilizes in time, while the wear of the back edge evolves continuously and leads to the loss of the cutting capacity of the tool edge therefore as a criterion for assessing the wear of the active part of a tool has been chosen the average width of the wear facet, *VB*, as its average value along the edge length, excluding the maximum value VB', fig. 2. The latter appears on the tool edge where produce the cutting of surface layer of the workpiece, a layer with a higher hardness than the rest of the material, due to hardening due the effect of the cutting efforts. The VB' value does not characterize the actual wear of the tool edge [1], [2], [5],[6].

It is customary to represent in wear-time coordinates the evolution of *VB* wear of the tool edge, the influence of other factors such as cutting speed *v* or feed *s* occurring through families of curves, figure 4, called wear characteristics. On a certain wear characteristic the following elements are defined:

- wear rate, *I*, as the value of the slope of the characteristic at a certain point, $I = tg\varphi$;
- the average wear rate, *Imed*, as the value of the slope of a straight line passing through the origin and is tangent to the wear characteristic, $I_{med} = tg\varphi_{med}$.

2 The influence of Different Factors on the Wear of Cutting Tools

Researching the dependence of wear depending on the elements of the cutting regime is an activity that consumes a lot of time and materials (semi-finished products, tools). For example, the experimental tracing of a single wear curve of the type in Figures 3,4,5 involves cutting for tens of minutes, periodically interrupted to measure tool edge wear (a measurement can take 1 ... 3 minutes), to which is added a consumption of about 1 ... 10 kg of semi-finished product and the consumption of a tool edge, unusable without a re-sharpening (with geometry, roughness, metallographic structure identical to those of the previous edge) or replacement. A complete study, for only one pair of workpiece-tool, involves drawing at least 10 wear diagrams. This clearly shows the great effort that must be made to do so.

The greatest influence on the characteristic dimensions of wear has the cutting speed as shown in the diagrams in figure. 6, 7 and 8.

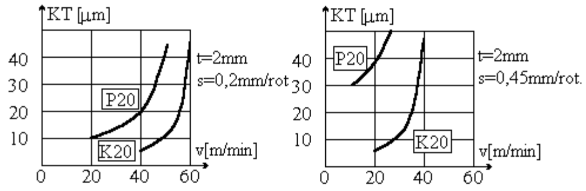

Figure 6 The wear on the front face

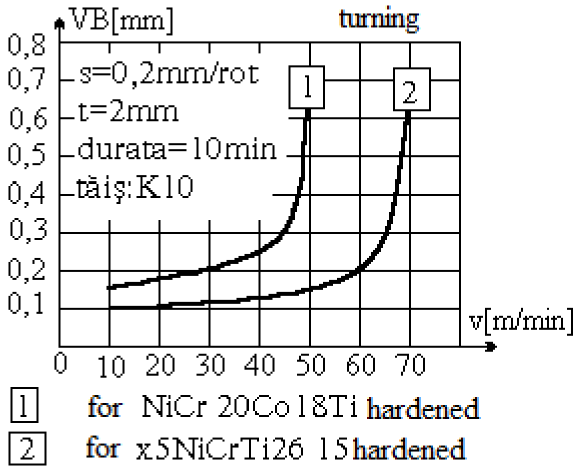

Figure 7 The influence of speed on wear

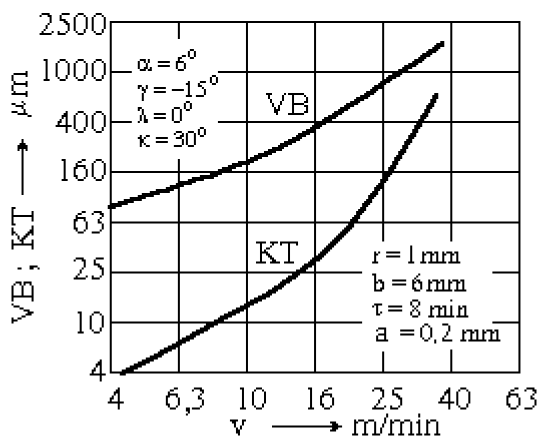

Figure 8 Variation of the characteristic dimensions of the wears depending on the cutting speed

Experimental laboratory research as well as the practice of using cutting tools have shown that among the elements of the cutting regime, speed has the highest weight on the wear rate and durability of cutting tools.

The first studies performed in this sense highlighted a functional link between *T* and *v* in the form of linear functions if instead of the variables *T* and v are considered their logarithms, as shown in the diagrams in figure 9 in logarithmic double coordinates.

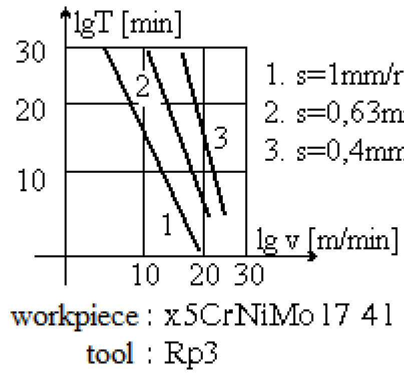

Figure 9 Linear dependence between speed and durability

The mathematical expression of the functional connection, known by several names (Taylor's equation, velocity equation, or durability equation) is still accepted today:

$$v = \frac{C_v}{T^m} \qquad (1)$$

Equation (1) can be generalized by including all the elements involved in the cutting process, becoming:

$$v = \frac{C_v \cdot k_1 \cdot k_2 \cdot \ldots \cdot k_n}{T_{ef}{}^m \cdot t^{x_v} \cdot s^{y_v} \cdot (HB)^{n_v}} \qquad (2)$$

The equation is approximate on large value ranges of the variables *t*, *s*, *v* but has the merit of making a functional connection between the value of durability and the values of the parameters of the cutting regime.

Research has shown that at very high speeds there is a decrease in cutting temperature, resulting in a corresponding reduction in wear and an increase in the durability of the cutting edge tool.

Thus, it was concluded that, depending on the material of the workpiece, from a certain value of the cutting speed upwards, there is no increase of the cutting temperature, appearing even a very significant decrease of this temperature figure 10.

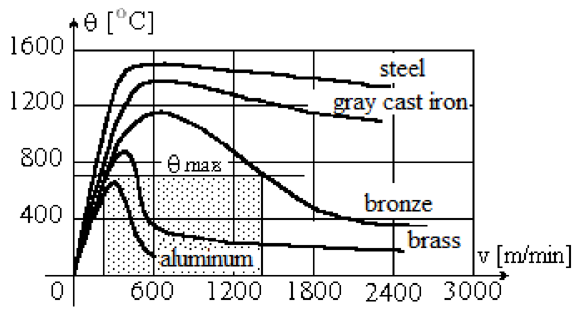

Figure 10 Influence of cutting speed on cutting temperature

Table 1

Material	Chemical composition %							Hardness HB
	C	Si	Mn	Cr	Cu	S	P	
Fc 200	3,30	2,40	0,86	0,10	0,35	0,025	0,06	160-180
Fmp 650	2,31	0,37	0,32	0,067		0,030	0,1	240-260
Fgn 500	3,63	2,63	0,36			0,01	0,02	200-230

Table 2

Material	Chemical composition %					Hardness
	C	Si	Mn	Cr	Mo	HB
Steel 8550 workpiece material	0,30 - 0,37	0,15-0,40	0,40 - 0,70	1,50-1,80	0,15-0,25	200
35 C 10	0,31-0,39	0,17-0,37	0,50-0,80	0,8-1,1	-	197
33 Mo C 11	0,30-0,37	0,17-0,37	0,40-0,80	0,90-1,30	0,15-0,30	217
25 Mo C 11	0,22-0,29	0,17-0,37	0,40-0,80	0,90-1,30	0,15-0,30	217

The temperature of the chip increases as a result of its supply with energy coming exclusively from friction, from the friction between the chip and the tool and from the inter- and intracrystalline frictions that appear in the process of chip formation and detachment; as the temperature increases and the chip becomes more plastic, certain areas of it reaching the liquid phase, the above frictions decrease in intensity leading to lower energy releases, so lower chip temperatures, temperatures that make the chip become more solid, more intense frictions that tend to raise the temperature again and so on; so there is a combination of effects with opposite tendencies whose end result cannot be a chip temperature equal to the melting temperature of the part material, but an equilibrium temperature below the melting temperature.
The ensemble of elements and factors that govern the temperature (implicitly also the wear) in the cutting area is very comprehensive, forming in fact a system composed of workpiece, chip, edge and medium. The phenomena must be treated in a unitary way, in total interdependence both internally (connections and influences between the elements of the system) and externally (connection with the environment by radiation, covection, etc.).
The systemic non-treatment so far has been caused by the complexity of the system and the lack of practical means of investigation on physical-mathematical models.

3 Experimental Results on Tool Edge Wear

The researched edge variants correspond to the types of plates presented in figure 11.

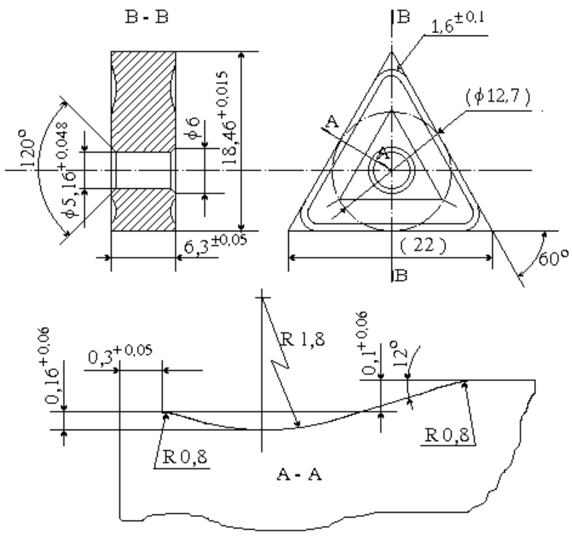

Figure 11 Replaceable plate TNMG, Material groups P and K

Steel 8550 was chosen for the research, the chemical composition and hardness of which compared to current materials are shown in Table 1, and for cast iron the materials used were according to Table 2.
For the experimental research itself it was necessary to establish the fields of the parameters of the cutting regime, so that they could be used in the most comprehensive cases. Were taken

into account the cutting regimes used on commonly used semi-automatic machine tools. For experiments, the upper limit of the cutting speed was taken much higher than the usual speeds, to test the behavior of the plate and in samples in the most difficult regime to reduce the duration of the samples.

The program of experiments, as a number of samples and as values of the parameters of the cutting regime for each sample, was established based on statistical methods of data processing and planning of experiments.

For each plate, as a type and group of use, an experimental research program was established consisting of 12 samples, from which six samples were selected.

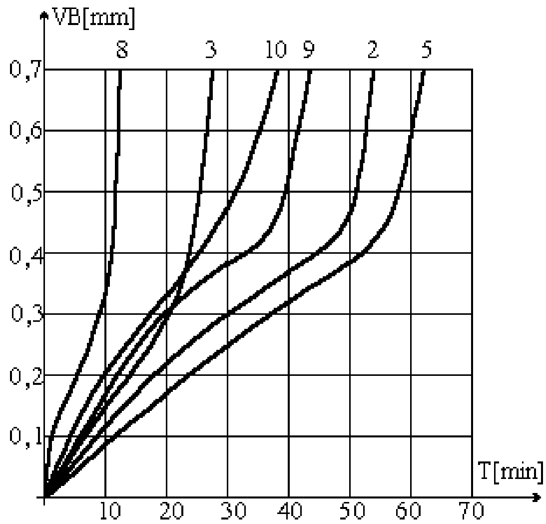

Plate covered with TiN

test	v[m/min]	s[mm/rot]	t[mm]
2	350	0,16	0,5
3	275	0,315	0,5
5	275	0,16	1
8	350	0,315	1
9,10	310	0,224	0,7

Figure 12 Wear VB of the plates when turning the steel

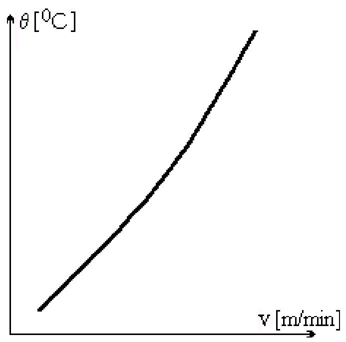

Figure 13 Temperature variation with cutting speed

The data collected during the experiments were synthesized in wear diagrams *VB = f (T)* for different working conditions, diagrams like those presented in figure 12.

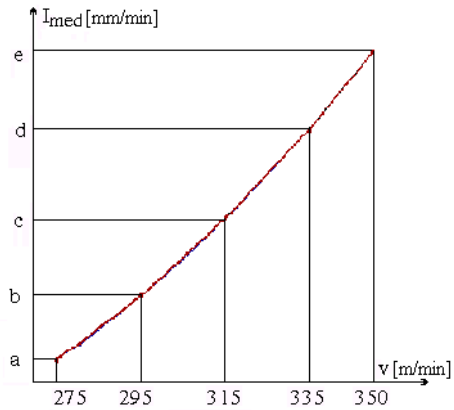

Figure 14 Variation of the average wear rate with the cutting speed

With the data obtained by physical-mathematical modeling of the thermal state in the cutting area, the temperature dependence as a function of velocity can be expressed mathematically through a relation of form:

$$\theta_{max} = 1001 - 2{,}38 \cdot v + 4{,}71 \cdot 10^{-3} \cdot v^2 \qquad (3)$$

The above relation was obtained based on the interpolation of the temperature values as a function of speed and has the graphical representation in figure 13, which highlights, first of all, the allure of the curve, the numerical values resulting from the expression itself (3).

The similarity can be seen between the allure of the curve $\theta^0C = f(v)$, figure 13 and the allure of the curves $I_{med} = f(v)$, figure 14.

From the relations $I_{med} = f(v)$ and the relation $\theta^0C = f(v)$ a direct relation can be deduced. In the case of a P10 type metal carbide (experiment in Figure 14), for which the friction coefficients were determined and the thermal fields were modeled, the proposed relationship becomes:

$$I_{med} = -0{,}0634 + 7{,}2438 \cdot 10^{-5} \cdot \sqrt{212{,}31 \cdot \theta - 148705{,}6} + 9{,}7663 \cdot 10^{-5} \cdot \theta \qquad (4)$$

The graphical representation of the relation (4) is given in figure 14, where, first of all, the allure of the curve is highlighted, the numerical values resulting from (4).

From the analysis of the graph shows the good proportionality between the average wear rate, Imed, and the maximum temperature in the cutting process, a fact found experimentally and presented in the literature.

5 Conclusion

Experimental research on tool edge temperature and average wear rate has established similarities between the evolutions of the two phenomena. Therefore, modeling the evolution of the thermal phenomenon can determine the evolution of the average wear rate by applying a proportionality constant, a constant that can be determined experimentally and which remains the same for the same couple chip -edge of tool.

The elements that contribute to the cutting process have less or greater influences on tool wear and therefore on their durability. Analyzing the influence of the same elements of the cutting regime on the temperature of the tool edge, one notices a similarity of the allure of the curves with those of their influence on the wear rate.

This comparative analysis leads to the conclusion that the variation of the average wear rate as a function of the elements of the cutting regime is similar to the variation of the temperature of the cutting edge as a function of the same elements of the cutting regime. As the cutting temperature can be measured much more easily, this parameter can be adopted as describing an anticipated measure of tool blade wear.

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