MATHEMATICAL MODELLING OF THERMAL AREA IN CUTTING TOOL

Daschievici Luiza, Ghelase Daniela and Goanta Adrian
Dunarea de Jos University Galati, Faculty of Engineering from Braila, Calea Calarasilor, nr. 29, Braila, Romania
Luiza.Tomulescu@ugal.ro, Daniela.Ghelase@ugal.ro, Adrian.Goanta@ugal.ro

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Abstract: Since experimental researches regarding cutting process have stated a proportionality dependence of wear medium intensity on cutting area temperature and because this fact was avoid or ignored by thorough studies and researches, we considered to be helpful developing a physical-mathematical model able to correlate the two phenomena: wear and temperature in the cutting area. The complete and correct research on thermal phenomena in the cutting area is possible only by taking into consideration the feed-back relation between the physical and phenomenological elements of the studied tribosystem and also, by taking into account the splinter movement, resulting in a continuous supplying with cold layers of the splinter area and in heat evacuating by warm splinter movement.

1 RESEARCH ON METAL CUTTING, SPECIFIC PROCESSES AND PHENOMENA

Metal cutting, due to the action of tool blade pushed on the processed material, leads to a complex status of forces and deformations in the cutting area.

This simple diagram is the base for any detailed study on cutting process. It is a basic physical model, completing other specific models of elasticity and plasticity, thermodynamics, tribology, thus forming a complex model, more or less detailed according to requirements or claims. For almost 100 years of researching on cutting process, many theoretical and experimental data have been gathered, but they are far beyond from being a unitary whole.

The present paper develops on this quite applicable, enough explored, but still insufficiently understood field of application.

Based on the knowledge, the definition of the splinter appearance process has been stated, containing also the essence of interdisciplinary aspects.

The essence of these aspects is already shown in the specialty literature, in detail, and this paper deals only on those aspects considered able to be improved.

The analysis of some definite aspects solving manner presented in the specialty literature led to the conclusion that errors have been done, errors able to stray from the real status.

The main phenomena and processes accompanying the cuting process are friction, tribosystem heating and tool wear. The tribosystem, consisting of tool, processed part and splinter, can be considered as a system with direct contact, where no lubricating film is present. Based on his own researches and taking into account some results of his predecessors, Coulomb stated the three dry friction rules, which are often partially confirmed. It can be reminded that friction depends on the relative speed, this fact being experimentally ascertained at the beginning of the XIX century, as shown in figure 1 (Tomulescu, 2000).

The experimental researches dawn up so far led to the conclusion that dry friction force depends on many factors such as: the normal pressure force, the relative sliding speed, the type of the contact and the value of the contact area, the quality and the roughness of the surface, the nature of materials in contact, the character of the friction areas: rigid or elastic, tenacious or fragile. Even human and materials resources were highly implied in research, the complex friction phenomenon did not allow a universal valid theory elaboration, for at least from the quality point of view.

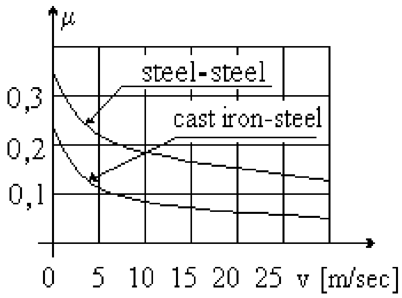


Figure 1: The variation of friction coefficient on speed.

Taking into account the prevalent role of friction on tribosystem parts heating, thus influencing the cutting tool wear, one considered necessary to do a research on he friction coefficient for a specific cutting case and highlight the fact that the friction coefficient is a non-coulombian one (Tomulescu, 1999; Tomulescu, 2003).

As for the dry or lubricated cutting friction, its framing in the dry friction category is based on the finding that the cooling fluids do not enter into the friction area.

The researches shown that the mechanical work necessary for volume plastic deformation in the cut metal layer is partially transformed into caloric energy that heats the cutting area; this process depends on the thermal conductivity of the cut metal and on the working conditions of cutting process.

The mechanical work consumed in the cutting process can be expressed by the next equation (Dumitras, 1983):

$$L=L_1+L_2+L_3+L_4+L_5+L_6 \quad (1)$$

where:

L_1, L_2 and L_3 are parts of the mechanical work transforming into heat during cutting and dispersed in the environment through the splinter, the tool and the processed part;

L_4, L_5 and L_6 are parts of mechanical work, consumed in the cutting process, with little values comparative with L_1, L_2 , L_3,.

The mechanical work consumed in the cutting process, entirely transformed in heat, L_1, L_2 and L_3 components, generates the heating sources Q_1, Q_2 and Q_3, fig. 2, ordered by their intensity, as follows: $Q_1>Q_2>Q_3$.

In fact, depending on the cutting process, different heat exchanges may develop between the processed part, the splinter and the tool, depending on the cutting process nature, so that the temperatures in the splinter, the tool and the processed part being not abided by the distribution of sources intensities.

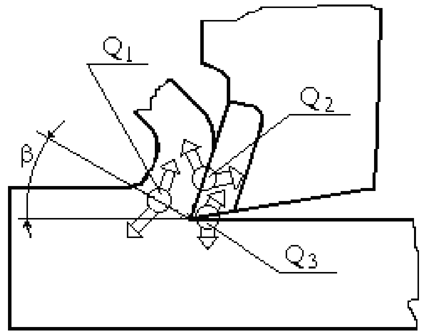


Figure 2: Mechanical work heat dispersing.

The factors influencing the heat generated by the cutting process are:

- the physical and mechanical characteristics of cut metal
- the cutting tool material
- the geometrical parameters of the tool
- the parameters of the cutting conditions

Since the blade temperature is the main wear-influencing factor, the researches went towards finding the empiric relations between blade temperature and the main cutting tool elements, less interest being paid to the aspect of heat quantities evaluation.

The blade wear behaviour depends in a large measure on its temperature. The experimental researches performed so far show that there is some proportionality between wear intensity and blade tool temperature, the variation rules demonstrating obvious parallelisms. That is why, in order to accurately evaluate wear intensity (and wear evolution) depending on cutting parameters, it is necessary to know the cutting temperature, including the tool blade temperature, depending on the cutting parameters.

Based on the researches performed, a series of dependence relations between the tribosystem elements temperatures have been defined.

The mathematic model shown by the specialty literature suits to an uniform stationary thermal status, respective to the same temperature in the entire splinter and tool blade and time constant, quite far from reality even for a qualitative and phenomenological analysis (Dumitras, 1983).

The hypothesis taken into consideration, according to which heating in the cutting area is uniform and stationary can be appreciated as a particular case that cannot be real.

That is why a specific model is required for the heating sources, able to lead to a correct determination of real thermal status, non-stationary and non-uniformly distributed, that, in time, leads to a stationary and non-uniformly distributed thermal status, depending on the influencing factors, the most important of them being as follows:

- the cutting process parameters;
- the physical and mechanical properties of the tool blade and splinter;
- the environmental heat exchange;
- the feed-back interdependence between different influencing factors;
- the cutting process dynamic phenomena.

Cutting wear comes up because of interfering factors effects and it is important to be known, especially regarding the cutting tool.

Tool wear is progressive and it manifests under many aspects (temperature increasing, processed area deterioration, cutting forces increasing), finally leading to their stop functioning.

The researches highlighted more blade wear types, as shown in figure 3 that represents these wear influences and makes possible an appreciation of their weight as part of total wear. The diagram shows that the abrasive wear has the highest influence; it is determined by the friction conditions of areas in contact: tool - processed part-splinter.

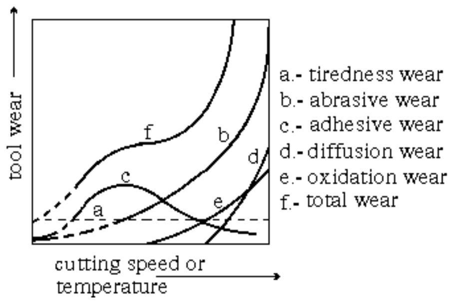


Figure 3: The influences of partial wear on total wear.

The splinter temperature increases due to the energy exclusively obtained from friction: the friction between the splinter and the tool and the friction between inter- and intracrystals that comes up during splinter formation and separation. The higher the temperature the more plastic is the splinter, some of its areas pass to the liquid phase, the intensity of the above mentioned frictions decreases, smaller amounts of energy are freed, splinter temperature decreases, the splinter is more solid, more intense frictions develop tending to increase the temperature, and so on. Therefore, a combination of effects with opposite tendencies takes place leading to a splinter temperature, which is not equal to the melting temperature of the processed part, but an equilibrium temperature beyond the melting one. Speed increasing, especially for high cutting speed, leads to a feedback chain, according to figure 4.

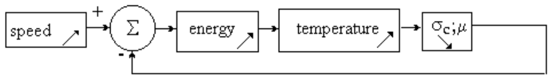


Figure 4: The feedback influence of temperature increasing on the mechanical characteristics of the processed material.

According to this chain, cutting speed increasing leads to cutting area temperatures increasing, the effect is a deformation resistance and mechanical work decreasing, thus implying wear reducing and a higher tool durability.

The analysis of cutting conditions influence on the tool temperature and tool wear leads to the conclusion that the variation of wear medium intensity is very similar to the variation of the temperature on the tool.

The main objective of the present paper is to combine in a single model the dynamic, thermal and tribologic phenomena, in order to evaluate in advance the wear intensity and to find out the way to influence it.

2 THE RESEARCH METHODOLOGY AND THE UTILIZED MANNERS

Among the considered objectives, there can be mentioned:

- the research of dynamic phenomena;
- the research of thermal and wear phenomena.

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 modelling. The model has mathematical equations, functionally describing the physical model, and through it, the real phenomenon. For mathematical model solving, difficult to be analytically solved, there have been used numerical methods to obtain solutions for the differential equations (Tomulescu, 2000).

The stages covered for phenomenon modelling are, as follows:

- cutting area forces modelling, based on Merchant model for free orthogonal cutting, where is taken into consideration the fact that the splinter is balanced by two categories of external and internal forces (Tomulescu, 2000);

- Heating Sources Modelling, figure 2;

It is thought that the heating source consists both by the non-conservative mechanical work wasted by plastic deformation in the cutting plane area and by the non-conservative mechanical work from the friction on the escaping and on the laying tool area.

- Heat Dispersing Modelling. The heat disperses into a non-homogeneous environment consisting of splinter, blade and tool body, each having different caloric coefficients, both as value and temperature dependence.

Solving the problem of heat dispersing under transitory conditions and in a heterogeneous environment leads to temperature knowing for every moment and in each point of the considered environment.

The theoretical study program, including the above-mentioned models, materialized in a very complex physical and mathematical computer model, enables the researching of the influence of different factors, such as:

- the parameters of the cutting conditions (speed, advance, depth);
- tool blade material;
- the cutting manner (continuous or interrupted).

As previously shown, the friction in the cutting area takes place under very particular conditions, such as high pressures, relative high-speed values, no lubrication. The bibliographical research shows that coulombian friction is an exaggerated approximation of dry friction.

As long as a realistic mathematical model is desired, the friction model for the cutting area should have a friction coefficient depending on speed for the couple splinter-blade.

By mathematical modelling, the differential equation for heat conducting is:

$$\rho \cdot c \cdot \frac{\partial \theta}{\partial t} = \lambda \cdot \left(\frac{\partial^2 \theta}{\partial x^2} + \frac{\partial^2 \theta}{\partial y^2} + \frac{\partial^2 \theta}{\partial z^2} \right) \quad (2)$$

that for an anisotropic and non-homogeneous material generally turns to:

$$\frac{\partial}{\partial t}(\rho \cdot c \cdot \theta) = \frac{\partial}{\partial x}\left(\lambda_x \cdot \frac{\partial \theta}{\partial x} \right) + \frac{\partial}{\partial y}\left(\lambda_y \cdot \frac{\partial \theta}{\partial y} \right) + \frac{\partial}{\partial z}\left(\lambda_z \cdot \frac{\partial \theta}{\partial z} \right) \quad (3)$$

where:

ρ - material density (kg/m^3);

c - material specific heating (J/kgK);

λ_x, λ_y, λ_z - material thermal conductivity (W/mK).

The integration of the differential equation (3) is analytically difficult to solve, and the specialty literature does not offer exact solutions for each practical case. To obtain an analytical result, the following solution is used:

$$\theta(t,x,y,z) = T(t) \cdot F(x,y,z) \quad (4)$$

replacing it in heat equation (3) leads to:

$$\rho \cdot c \cdot \frac{\partial T}{\partial t} \cdot F(x,y,z) = T(t) \cdot \left[\lambda_x \cdot \frac{\partial^2 F(x,y,z)}{\partial x^2} \right] + T(t) \cdot \left[\lambda_y \cdot \frac{\partial^2 F(x,y,z)}{\partial y^2} + \lambda_z \cdot \frac{\partial^2 F(x,y,z)}{\partial z^2} \right] \quad (5)$$

Heat exchanges inside and on the areas of the tribosystem the mathematic model, knowing the border conditions, extremely difficult to be analytically described, materializes elements and that is why numerical integration is preferred, the most suited being the finite differences method.

The friction coefficient used by the computing program was experimentally determined by using energetic methods.

The results obtained for the friction coefficient clearly led to the conclusion that, in this case, the friction is non-coulombian (Tomulescu, 2003). Its dependence on speed is shown in figure 5.

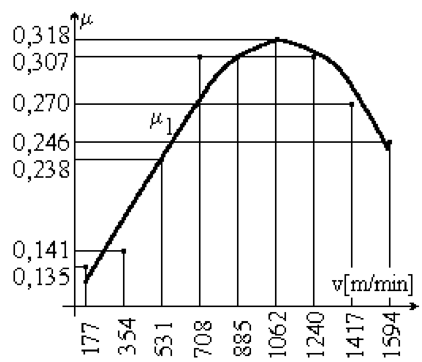
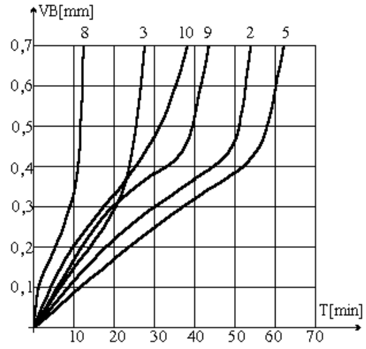


Figure 5: The variation of friction coefficient on relative speed.

The present paper also uses the results obtained by a classical research regarding tool wear, results taken out from a research project performed for manufacturing assimilation of metallic carbide cutting plates. These results were synthesized in wearing diagrams, VB = f(T), as shown in figure 6, for some specific processing cases. These wear curves, continuous in time, enabled the study of wear evolution correlated to the suggested mathematical modelling.



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 6: VB wear of TNGG 22.04.12/P10 plates for steel lathing 8550/97HB.

Taking into account the fact that the speed mostly determines process thermal status, with implications on cutting tool wear, it was considered necessary to be analyzed for the heating process, especially on the laying area, in order to diminish the implications and wear reducing.

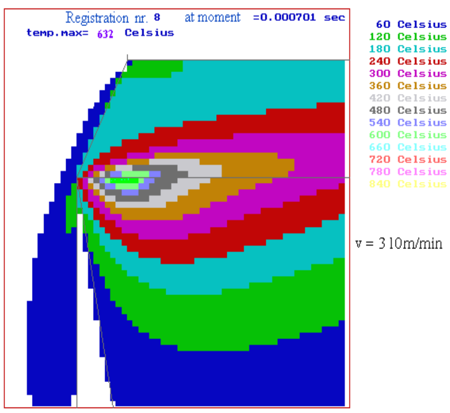


Figure 7: Thermal status in splinter-tool tribosystem.

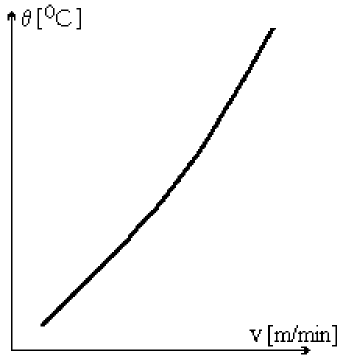


Figure 8: The variation of temperature on cutting speed.

By solving the mathematical model using the specialized developed program, thermal areas are obtained, as shown in figure 7; when analyzing for different cutting processes, with the required parameters *v*, *s* and *t*, appreciations on wear and durability of cutting tools can be stated. The obtained data can be used to trace a curve for temperature dependence on speed, as shown in figure 8 and the mathematic relation is:

$$\theta_{max} = 1001 - 2{,}38 \cdot v + 4{,}71 \cdot 10^{-3} \cdot v \tag{6}$$

Notice the similitude between θ°[C] = f(v) curve and I_{med}=f(v) curve, figure 9; a direct relation I_{med}=f(θ°C) for case (P10) can be stated, as shown in figure 10 and mathematic relation proposed is:

$$I_{med} = -0{,}0634 + 7{,}2438 \cdot 10^{-5} \cdot \sqrt{212{,}31 \cdot \theta - 1487056} + 9{,}7663 \cdot 10^{-5} \cdot \theta \tag{7}$$

Diagram analysis concludes that there is a good proportionality of wear medium intensity with the maximum temperature of cutting process, an experimentally stated fact, also presented by the specialty literature.

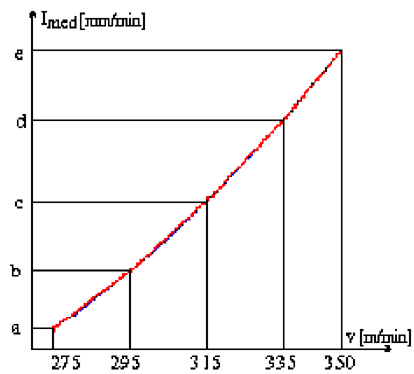


Figure 9: The variation of medium intensity on maximum temperature.

Experimental and theoretical researches regarding tool blade temperature and wear medium intensity settled up similitude between the evolutions of the two phenomena, leading to the conclusion that thermal phenomena evolution modelling enables the evolution of wear medium intensity, by applying a constant of proportionality, experimentally known, which remains the same for a couple splinter-blade.

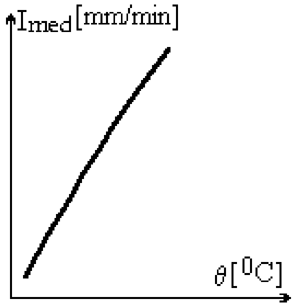


Figure 10: The variation of medium intensity on maximum temperature.

3 CONCLUSIONS

Based on the performed studies, a series of conclusions have been stated, among which are, as follows:

- the most important thermal sources, such as the source created by plastic deformations in the cutting plane and the source created by the friction between the splinter and the tool blade escaping area, have intensities and distributions depending on the values of the cutting conditions parameters and on the splinter-blade couple; they heat the cutting area to temperatures non-homogeneous distributed, and the temperatures influences those materials constants related to heating sources intensity;
- thermal status in the cutting area is characterized by a maximum in the splinter pressure center on the escaping area, as long as, in the wear area (the laying area) the temperature is much lower;
- it has been stated a dependence relation between a parameter characteristic tool blade wear, such as wear medium intensity, and cutting area temperature; the relation is, with pretty small deviations, a directly proportional dependence one; thus, by measuring the tribosystem temperature, the wear medium intensity can be evaluated, at least for the cutting process.

REFERENCES

Dumitras, C., Militaru, L., 1983. *Aschierea metalelor si fiabilitatea sculelor aschietoare.* Ed. Tehnica, Bucuresti.

L. Tomulescu, C. Falticeanu, Gh. Oproescu, 1999. *"Dynamic and thermal aspects of tribologic processes between tool blade and splinter during splitting"* - Balkantrib'99, The 3rd International Conference of Tribology, Sinaia,, ISSN 1221 - 9371, pg.233- 240.

Tomulescu, L., Ghelase, D., 2003. Experimental results obtained by friction process researching in processed part – tool tribosystem in cutting area. *International Science and Engineering Conference Machine - Building and Technosphere of the XXI Century* - Sevastopol, Ukraine, ISBN 966-7907-12-0, pg. 267 – 271

Tomulescu, L., 2000. *Tribologia taisului de scula aschietoare.* CEPROHART, Braila.