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SIMULATION MODELING OF CARBIDE TOOLS WEAR

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Annotation. The main objective of this paper is to demonstrate a way to use the simulation modeling in the tribology of metal cutting. The computer model is based on a compilation of the analytical models of the abrasive, adhesive and diffusion wears, after empirical particularization of the participating in them coefficients. The built-in stochastic generator simulates the real process of machining alloyed and nitrogen containing steels when they are with different properties. In more details is analyzed the abrasive wear caused by the presence of carbide and nitride inclusions in the structure of these steels . This approach allows to determine the wear and to estimate the tool life depending on change of the cutting data. The comparison of the results obtained by means of the simulation modeling and those from the real experiment is encouraging and shows that the modeling is very useful for carrying out research on such sophisticated process as the tool wear.

1. INTRODUCTION

The mathematical modeling of the cutting process is accompanied by many obstacles due to the insufficient knowledge of the chip formation, the tribologycal and thermodynamic phenomena at this stage of the science. In the theory of cutting it is accepted that they are function of many factors, a portion of which have stochastic character [10]. Direct observations of the cutting process are not possible without use of special instruments or methods, which in all cases result in deformation of the real process.

The wear of the cutting portion of the tool and its life are of paramount importance in the metal cutting, since the overall performance of the tool and the machining economy are determined by the essence, the values and the mechanisms of the wear [2, 4]. The wear is a combination of sophisticated chemical and physical-mechanical phenomena, restricted in small volumes located on the face and flank surface. Those phenomena occur at very high temperatures (around 1000-1200° C) and pressures (up to 1 - 1.5 GPa), as well as with intensive friction (μ = 1 - 1.5). The numerous theories considering the wear are based on hypothetical assumptions, analyzed phenomena and on received results, rather than on the reasons for it [6]. Despite the obvious significance of such theoretical approach, the practice needs more direct and more pragmatic methods for estimating the performance of the tool at certain working conditions. The research work is directed mainly towards determination of elementary functional dependencies considering the influence of process input factors, as cutting data, tool geometry, properties of the workpiece and tool materials, on the output parameters - wear and life of the tool [7]. The experimental obtaining of these dependencies requires a great amount of work and time, participation of skilled staff and spending of big funds. The inclusion of more than three factors in the experiments leads to considerable increase of its volume and cost, what is the reason that such approach practically is not employed. The influence of dozens of independent variables on the wear makes almost impossible the obtaining of the same equations in the seemingly same conditions. In [7] is made an attempt for complex estimation of the direct and indirect influence of many of the factors acting upon the wear and life of tool by means of "multiplicate models". From the view points of the tribology and the production, it is necessary that the model is able to react adequately to a change of the multitude of basic variables and provides possibility for study of their influence on the wear. An up-to-date way for study is the simulation model [4, 7].

In this paper is applied the method of modeling which corresponds to the specificity of building a simulation procedure of the wear mechanisms. A stochastic generator is included which is modeling a random combination of mechanical properties of the workpiece within their permissible limits, thus simulating the real process. The model simulates the machining of a batch of workpieces with different properties and in a certain succession, when, with the same conditions of cutting, a dispersion of the tool life is obtained. The reasons to apply the simulation modeling are :

a) relatively more extensive reflecting of the influence of factors in non-working conditions, what diminishes the drain of material, labour and time for experimenting;

b) obtaining of fuller and more accurate information that can not be obtained in real conditions;

c) obtaining at any moment results for the wear and possibility for their visualization.

2. THEORETICAL PART

The total volumetric wear is a sum total of the volumetric wears due to the action of the abrasive, adhesive and diffusion mechanisms. To the separate wear mechanisms correspond hypotheses by means of which is described the sophisticated and still insufficiently explained general character of the wear [6].The model is open and allows, if necessary, its supplementing with new corrected equations or wear mechanisms. The application of the principle of superimposing, provides the possibility to use together the different models that are suggested to describe the wear mechanisms, without their reciprocal exclusion.

The relative participation of the various wear mechanisms in the total wear of the cutting part, depends mainly on the change of the contact temperature, which dependence is not monotonous. The temperature at which the dependence has a minimum does not depend on the working conditions and is constant for each pair machined / cutting material.

For the purpose of the simulation is used a discreet form of the wear equations, with time step $\Delta\tau$. For the basic wear mechanisms are applied the physical considerations and the equations used in the simulation model.

Abrasive wear. The hard non-metallic inclusions in the machined material - carbides, nitrides and carbonitrides - have a strong abrasive effect. According the author's opinion, for hyper-eutectoid steels of the Hr12.Mo.V type, the abrasive wear of the cutting part is with relatively highest share in comparison to the remaining wear mechanisms. The model for the abrasive wear is developed on the following assumptions: a) the wear has only a mechanical character ; b) only the influence of non-metallic inclusions is considered; c) the non-metallic (carbide) inclusions are absolutely non-deformed , have a spherical shape with a conditional mean diameter and are distributed according a normal distribution law within the volume of an elementary cube [11].

The model of the abrasive wear has the appearance:

(1) $$\Delta W_{abr} = \Delta H^2 \frac{b}{2}\left(\frac{1}{tg\alpha_0} - tg\gamma_0\right),$$

where Δ H is the depth of the wear land obtained during the time of machining $\Delta\tau$, defined from the function

(2) $$\Delta H = C_1 \beta \frac{q_N}{H_t} (pa)^{2/3} V \Delta\tau ,$$

where C1 is the constant; β - the probability a certain particle to perform wear; (β = 0.11); q_N - the contact stress; H_t - the hardness of the cutting material pa - the concentration of abrasive particles; b - width of cutting; α_0 , γ_0 - geometrical parameters of the tool.

Adhesive wear. In the generated zone of contact between the tool and the machined material occurs strengthening of the surfaces and destruction at big depth. The model of adhesive wear is built on the following assumptions: a) the irregularities on both surfaces are with cylindrical shape, i.e. the surface of contact is permanent; b) adhesion takes place not in all contacts and this fact is reflected by the probability coefficient Z which depends on the ratio of the tool hardness H_t to the hardness of the machined material H_m. The hardnesses of the cutting and machined materials in the contact zone depend on the contact temperature θ_f : Ht = 19.85 - 0.013θ_f, GPa ; H_m =2.1 - 10^{-8} θ_f, GPa [5,9]. The model of the adhesive wear has the appearance:

(3) $$\Delta W_{adh} = C_2 Z \frac{H_{t0}}{H_t} \cdot \frac{q_N}{H_m} Vb \quad \Delta\tau ,$$

where C_2 is the constant ($C_2 = 2.10^{-3}$), $Z = 0.035 \left(\frac{H_t}{H_m}\right)^{-4.67}$ according Archard,

H_{t0} - the hardness of the cutting material at the temperature of the ambient media.

Diffusion wear. The model of diffusion wear has been suggested by Loladse [6] :

(4) $$\Delta W_{dif} = C_3\, b\, \theta_f^{\,1.8} \exp\,[C_4 / \theta_f + 273]\, VL_c\ \Delta\tau,$$

where C_3 and C_4 are the constants (C_3 = 1.808; C_4 = -2.10^{-4})

3. OBJECT OF RESEARCH

The cutting part of the tool was from material P25, shaped as an insert SNUN 120408 with permanent geometry and properties during all experiments. The machined materials were high-carbon tool steel Hr12.Mo.V and nitrogen alloyed steels Hr12.Mo.N007.V and Hr12.Mo.N017.V. A characteristic feature for the nitrogen alloyage is the obtaining of a new equilibrium condition and new carbide and carbonitride phases. The general volumetric share of the amount of carbide phases is from 13 to 17%, which considerably changes the character and the relative share of the wear mechanisms. The main carbide phase of steel Hr12.Mo.V is M_7C_3 and in the nitrogen steels appears a phase of the type MCN. For the studied steels, the ratio N/C varies from 0.02 to 0.22; for larger values, the amount of carbides diminishes and rises the amount of the carbonitrides. The chemical composition of the steels was within the prescribed by the standard limits and the hardness was (223 $\pm$ 3) HB.

From metallographical analysis of the studied samples were obtained:

- mean statistical conditional diameter - D_k = 1.30 - 1.90 μm;
- mean statistical hardness HB = 1450 - 2250 daN/mm^2;
- mean linear distance between the grains H_k = 10 -25 μm.

4. SIMULATION MODELING

The simulation model is built on the following assumptions:

1. The wear of the tool cutting part when machining the high-carbon steel Hr12.Mo.V and the nitrogen alloyed steels Hr12.Mo.N007.V and Hr12.Mo.N017.V is due mainly to carbide (carbonitride) inclusions in the machined material, while the influence of other non-metallic inclusions is neglected.
2. The carbide grains are absolutely non-deformed and are with spherical shape with mean diameter D.
3. The distribution of the hardness and the mean diameter of the carboinitrides is according a two-dimensional normal law.
4. The continuous cutting process is transformed into a discreete one, with a very small time increment ($\Delta\tau$ = 1s).

The total volumetric wear of the tool cutting part is estimated as a sum of the results from the simulation of the abrasive, adhesive and diffusion wear mechanisms at any time moment. By successive summing of the accumulated current size of the volumetric wear is determined the time elapsed till reaching the wear criterion (the tool life).

The algorithm of the simulation model contains the following modules and procedures:

1. Beginning. Input values are assigned: a)cutting data parameters (cutting speed V, feed S, cutting depth t); b) geometrical parameters of the tool (rake angle γ_0, clearance angle α_0, tool cutting edge angle k_r); c) parameters of the cut-away layer (thickness h, width b); d) hardness of the machined material H_0 and of the cutting tool H_t ; e) the volume of the material removed per unit of time; f) the volumetric wear criterion.

2. Additional information: a) the probable percentage content of carbide phase in a volume unit of the machined material; b) the number of carbide particles; c) determination of the normal distribution law for the carbide particles and presenting it in a two-dimensional table or histogram by means of the conditional mean diameter D and the hardness H_a.

3. Subprogramme for calculation of the abrasive wear: a) calculation of the normal force N depending on the conditional diameter D; b) calculation of h - the depth of penetration in the cutting material; c) calculation of f - the area of the cross section of the portion of the sphere that has penetrated in the cutting material; d) checking the diameter value - whether it complies with the requirement $2\,h/D \geq 0.01$, in order to provide possibility for abrasive wear; e) checking the carbide particles hardness - whether it complies with the requirement $H_a > H_t$ in order to provide possibility for abrasive wear; f) calculation of n - the number of abrasive particles per area unit.

4. Calculation procedure : a) calculation of the separate wears and the total volumetric wear and checking by means of the time measuring instrument; b) in case the total volumetric wear is smaller than the wear criterion, follows an iterative cycle. c) calculation of a new volumetric wear which lasts until the total volumetric wear becomes equal to the wear criterion.

5. End: a) displaying the size of the wear caused by the separate mechanisms; b) displaying the tool life.

The basic construction of the simulation model is built on analytical dependencies describing the mutual links in the real process. The adequacy problem is reduced to a detailed and precise description of all or main phenomena in the process of cutting and the wear. The computer simulation gives a good chance to model the process of cutting by means of simple procedures. The dissipation of the results obtained from the model is due to the built-in random value generators - the first for the size of the carbide inclusions, dealing with 7 subintervals within the limits 1.3 - 1.9 μm, and the second - with 9 subintervals within the limits 1300 - 2100 MPa. In one of the calculation steps was received a total number of the particles 589941, distributed according a normal law (fig. 1).

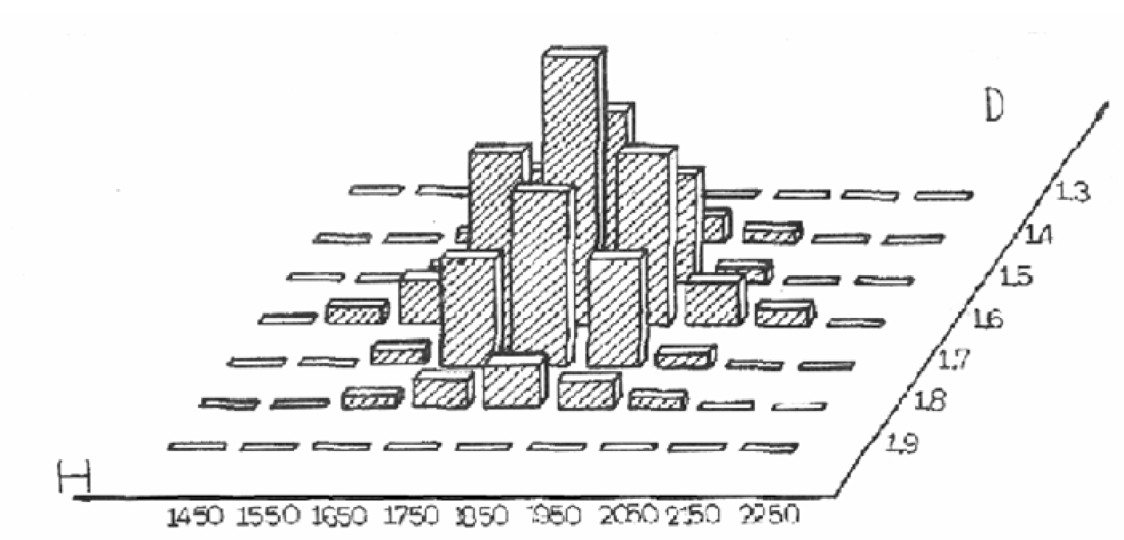

fig. 1

5. RESULTS

By means of the constructed simulation model, using cutting data: V_c = 100m/min, f = 0.42 mm/rev, a_p = 3 mm, were obtained: W_{abr} = 0.00773 mm^3, W_{adh} = 0.00397 mm^3, W_{dif} = 0.00034 mm^3, W_0 =0.01204 mm^3 = W_{kp} and time of work - tool life 13.55 min. In a real experiment of machining steel Hr12.Mo.V, employing the same conditions of work, the tool life was T = 12 min. The comparatively good coincidence between the results from the computer simulation model and the real experiment demonstrates the trustworthiness and adequacy of the created procedure. Similar accordance was obtained also in experiments employing other work conditions.

6. CONCLUSION

The constructed procedure of simulation modeling of the wear provides a possibility for obtaining and analyzing of results for the separate mechanisms and the whole wear at different working conditions . When machining high-carbon and nitrogen steels, the relative share of the abrasive wear is larger than the shares of the adhesive and diffusion wears.

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