FINITE ELEMENT ANALYSIS OF HEAT TRANSFER ON THE ACTIVE SURFACE OF CUTTING TOOLS

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ABSTRACT: *The finit elements method is a procedure of solving a large variety of engeneering problems with the assistance of the computer. In this paper we will analyze the way in which the heat distribution is made in the contact area between the part and the cutting tool using the ANALYSIS AND SIMULATION module from CATIA. This mode of design involves advanced knowledge of modeling, programming and management of parameters and relationships, being called parameterized assisted design.*

KEY WORDS: finite element, discretization, equation, heat, durability

1. INTRODUCTION

1.1. The principle of the finite element method

The finite element method is a process of roughly solving, with the help of a computer, a wide variety of engineering problems. These problems aim to determine, in a considered field, the values of one or more unknown functions, such as, for example, temperatures, pressures, speeds, displacements, mechanical stresses, specific deformations, etc., according to the nature of the treated problem. As the domain has an infinity of points, the values of the function are in infinite number [4].

1.2. The steps to solve a problem using the finite element method

The steps to solve a problem using the finite element method can be grouped as follows:

a) The division of the field of analysis into finite elements, also called discretization. Discretization consists in choosing the type of finite elements appropriate to the problem to be solved and dividing the structure into finite elements.

This stage is the most important from the designer's point of view because it is up to him to interpret and choose the best discretion, depending on the purpose pursued and the working conditions of the structure.

A finite element, of any shape and size, can be approximated with a "Φ" function on that domain, called the interpolation function or dereroxation function. The higher the degree of this function, the smaller the error of approximating the finite element with the function Φ. The approximation function can be written as [1], [3]:

$$\Phi = [N] \cdot \{\Phi\}_e \tag{1}$$

where:

[N] - function matrix of the form;

$\{\Phi\}_e$ - the vector of the nodal functions on the finite element.

b) Establishment of finite element equations and equational elementary.

These equations characterize the behavior of the material or environment within a finite element and can be deduced by several methods. The number of equations of the system is equal to the number of degrees of freedom per element.

The elementary equation, according to the energy balance method, has the form [1], [3]:

$$[k] \cdot \{\Phi\}_e = \{p\} \qquad (2)$$

where:
[k] - the stiffness matrix, which defines the physical-geometric characteristics of the material;
{p} - the load vector.

c) Assembling elementary equations in the system of equations of the structure.

The system of equations of the structure after assembly, has the form [1], [3]:

$$[K] \cdot \{\Phi\} = \{P\} \qquad (3)$$

The system has as many equations as the degree of freedom of the structure, ie the product of the total number of nodes and the number of degrees of freedom per node.

d) Solving the system of equations of the structure is done by one of the usual procedures.

2. FINITE ELEMENT CALCULATIONS IN HEAT CONDUCTION PROBLEMS

2.1. Heat transfer modes and heat conduction functionality

Heat transfer is the natural process of transferring internal energy from higher temperature to lower temperature bodies or, inside a body, from parts of a higher temperature to parts with a lower temperature. Heat is transmitted through conduction, convection and radiation [2].

- Heat conduction is the process of transmitting heat inside a body or between bodies in direct contact, from particle to particle, ie between atoms and molecules. Conduction is of particular interest in the case of solid bodies, less so in the case of liquid bodies and rarely in the case of gases.
- Heat convection is the process of transmitting heat from one part of the space to another through a fluid (thermal agent). Convection occurs only in the case of gases and liquids.
- Radiation is the process of transmitting heat in the form of radiant energy. In the radiant body the internal energy is transformed into radiant energy and is transmitted in the form of electromagnetic waves to the absorbent body, where the radiant energy is transformed into internal energy.

The temperature in a body is a function of the coordinates of the space x, y, z and the time t, of the form [2]:

$$\theta = f(x,y,z,t) \qquad (4)$$

This equation mathematically expresses the temperature field, ie the totality of the temperatures inside a body. If the temperature does not change over time, the temperature field is called stationary, and otherwise it is called stationary or transient. As the temperature varies according to all three coordinates of space, two of them or only one, the field is called three-, two- or one-dimensional, respectively.

Another way to solve thermal conduction problems is offered by the finite element method. In the variational approach of the method, the integration of the differential equation of heat conduction, in the limit conditions, is equivalent to the minimization of the functional [2]:

$$J = \int_V \left\{ \frac{1}{2}\left[\lambda_x \left(\frac{\partial\theta}{\partial x} \right)^2 + \lambda_y \left(\frac{\partial\theta}{\partial y} \right)^2 + \lambda_z \left(\frac{\partial\theta}{\partial z} \right)^2 \right] - \left(M - c \cdot \gamma \cdot \frac{\partial\theta}{\partial t} \right)\theta \right\} \cdot dV - \\ - \int_{S_2} q \cdot \theta \cdot dS + \int_{S_3} \alpha \cdot \theta \cdot \left(\frac{1}{2}\theta - \theta_E \right) \cdot dS \tag{5}$$

The minimization of the functionality is done, as in the case of elasticity problems, on finite elements, the overall effect being obtained by accumulating the contribution of each element. In the case of thermal conduction problems, there is only one parameter in each node - temperature, ie a scalar quantity.

2.2. Discretization of the model and choice of the finite element

Discretization consists in replacing the model with an infinity of points with a discrete idealized model (body), which has a finite number of points called nodes.

The principles on which discretization is performed are:

- the nodes must be contained on the inner and outer contour of the part (model), in the junction areas, load application, in the bearing areas and in all areas of interest;
- the internal nodes of the discretization network must be placed so that the network is as simple and uniform as possible;
- in order to obtain a satisfactory precision of the results, the discretization must be as fine as possible.

Figure 1 shows such a finite element [2], [4]:

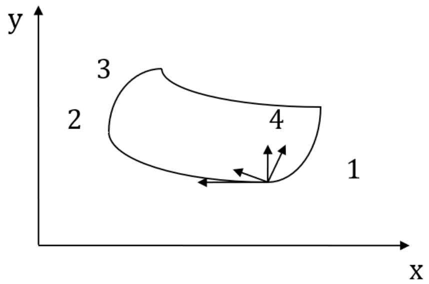

Fig.1. Nodal element in finite element analysis

3. CASE STUDY

3.1. Preparation of work samples

In order to perform the analysis, additional layers with a thickness of 1.5 mm of TiB_2 - 10% powder, respectively TiB_2 - 20% in 316L matrix were deposited on the clearance surface of some lathe knives made of RP2-1 / 2X11T carbon steel. . The deposition was performed at a temperature of about 1400 ^oC, with the presence of the liquid phase. The power of the laser installation was adjusted to 1W with a load factor of 40%. The molten 316L steel particles adhered to the molten surface layer of the base material (RP2-1 / 2X11T carbon steel). In the micrograph (fig.2) it is observed how the TiB_2 particles of size 2 ÷ 4μm are included in the 316L matrix.

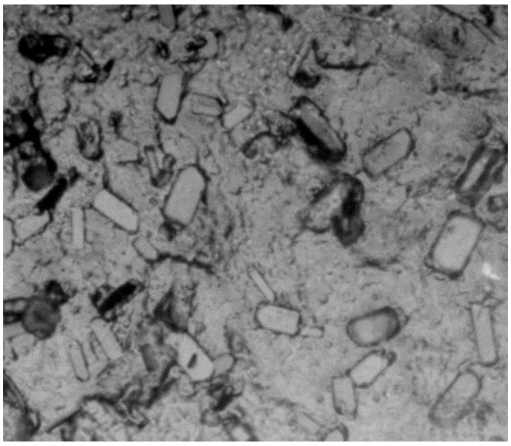

Fig.2. TiB_2 titanium diboride particles, in 316L steel matrix, on flat surface RP2-1 / 2X11T carbon steel (optical 400x).

3.2. Determinations performed on the lathe tools

Using a Vickers Reichert type microdurimeter, measurements were made of the microdurity of the deposited layers, at different depths, resulting in the following graph (fig.3):

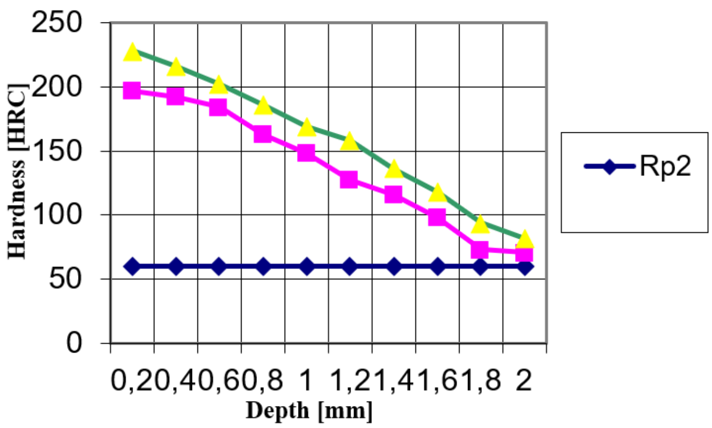

Fig.3. The configuration of the micro-hardnesses taken from the clearance surface of the lathe tools

The lathe tools on which a powder layer containing 20% TiB2 was deposited was subjected to working samples. During the use of the tools in the operation of cutting a semi-finished product, at different time intervals, temperature measurements were made at different points of the active part of the tools, resulting in the following distribution of temperature fields [5] (fig. 4).

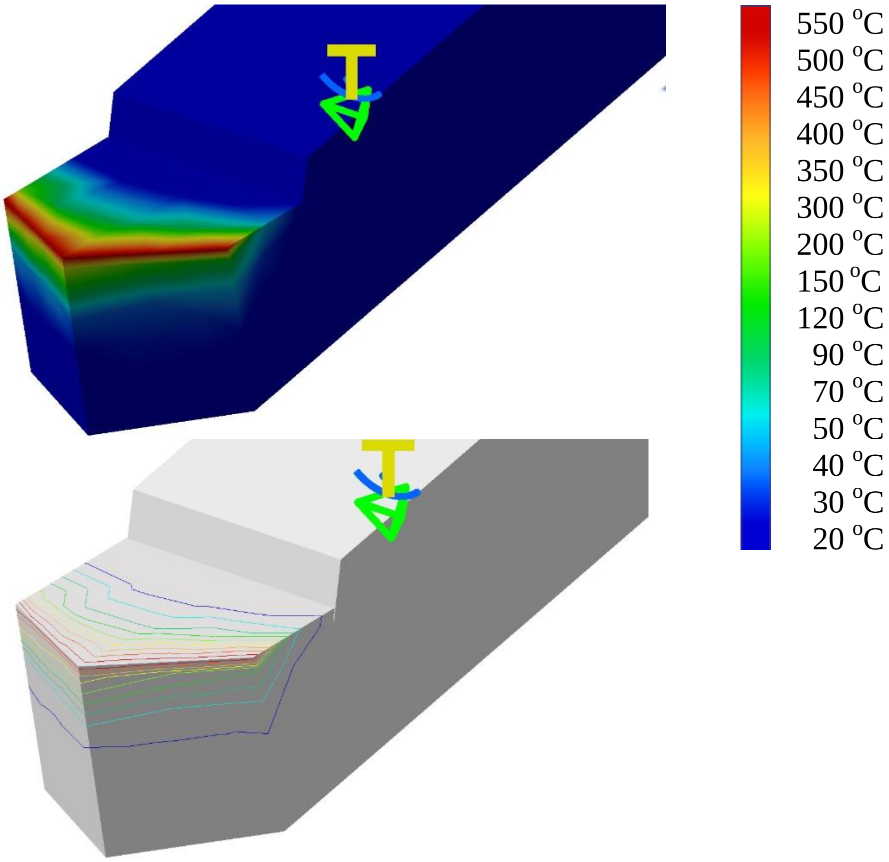

Fig.4. Distribution of temperature fields on the active surface of the tools

The deposition of a layer of TiB_2 powder (20%) in a 316L matrix led to a considerable increase in the working temperature of the knife. Measurements made on the knife before deposition showed a limitation of the working temperature to 420 – 480 ^oC.

Also, the durability of the knife has increased by about 70%. This was verified following the operation of a classic RP2-1 / 2X11T carbon steel knife and the sample knife. The checks were performed when cutting a C45 semi-finished product with a diameter of Φ 80.

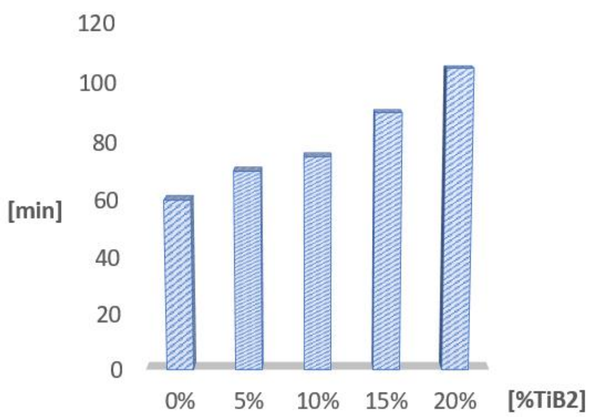

Fig.5. Durability of the lathe tools (RP2-1 / 2X11T carbon steel) depending on the concentration of TiB_2 (thickness of the deposited layer h = 1.5 mm).

During the experiments it was found that a maximum efficiency is obtained in the case of depositing a layer of 1.5 mm in a concentration of 20% TiB2.

The results obtained from the measurements of the applied variants are presented in the graph of figure 5, the optimal variant was the one with a layer of 1.5 mm in a concentration of 20% TiB2. It has been observed that for layers around 2mm or larger, small pieces of material come off the edge of the knife.

4. CONCLUSION

- The investigation by the finite element method of the working samples formed with different concentrations of powders, allowed the highlighting of some important aspects regarding the structure and hardness of these materials;
- Within the mentioned analyzes, successive areas were studied, following the structure and composition of the deposited layer, for different values of the sintering parameters;
-Determinations were performed on the work samples, being represented the configuration of the micro-hardnesses on the clearance surface of the lathe knife;
-The distribution of temperature fields on the active surface of the knife was analyzed;
-It was concluded that the deformation and fracture of sintered materials subjected to static and dynamic stresses, are influenced by the presence of pores in the structure of the material, the pores being stress concentrators that cause deformation and generate the priming and propagation of cracks.

REFERENCES

[1] Huebner, Kenneth – *The finite element method for engineers,* Fourth edition, 2001

[2] Lewis, R.W. s.a. – *The finite element method in heat transfer analysis*, British Library Cataloguing in Publication Data, 1996;

[3] Liu, G.R., s.a. – *The finite element method. A practical course*, British Library Cataloguing in Publication Data, 2003

[4] Maksay, Ştefan., Bistrian, Diana - *Introducere în metoda elementelor finite*, Editura CERMI, Iaşi, 2008

[5] Alin NIOAŢĂ - *FEM structural analysis of a shaping cutter using CATIA* - FIABILITY & DURABILITY, Nr.1/2019, may, ISSN 1844-640X, pp.184-189.