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Temperature Influence on Wear Characteristics and Blunting of the Tool in Continuous Wood Cutting Process

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Abstract

Temperature of the cutting tool is one of the most important factor affecting the tool wear in wood processing, because the basic properties of the material from which a tool is made, such as hardness, toughness and chemical stability, degrade with increasing tool's temperature. The effect of different wear mechanisms in the degradation of tools, cannot be estimated as accurately as possible without information on the temperature distribution in the tool and the impact of temperature on the basic material properties of cutting tools, especially in the most critical region, the edge of the tool.
Temperature distribution in the blade during the process of wood cutting was investigated by numerical means and compared with experimental and analytical results. In this study we have used the Boundary Element Method (BEM) to obtain numerical solution. It was found that the temperature of the blade depends on several factors, including the cutting speed, the continuity of the cutting process, the depth of cut and the shape of the tool.

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Keywords: wood cutting; temperature; boundary element method

1. Introduction

During the processing of materials by cutting, the main objective is to provide high quality machined surface with minimal processing costs. It is impossible to achieve without studying the thermal effects that are result of such processes. Thermal energy is generated by a continuous plastic deformation and shearing down of material at the

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chip formation, as well as the friction that occurs when moving chips on the front surface of the tool, also with friction between workpiece (working piece) and dorsal surfaces of tools. In this process, transient temperature fields results.

It is known that heat from the cutting zone mostly goes to chips, but it is also known that a significant part of the resulting heat is transferred to the tool and to the workpiece. The resulting heat negatively affects the quality and accuracy of the workpiece.

Determination of the temperature of the tool, chip and wood piece is important for the processes efficiency, because the change of temperature, have great influence on the rate of tool wear. Tool wear changes the cutting properties of the tool, and the tool wear is an indicator of its availability. The temperature distribution in tool is mainly investigated to show influence of main factors such as cutting speed [1,2], the depth of cut and the effect of sharpening angle [3,4]. Mainly, in this study the Boundary Element Method (BEM) is used to obtain numerical results of temperature distribution inside the tool. Those results will be correlated to experimental and analytical solution. The aim of this approach is to provide a realistic value of the cutting power into thermal energy, which occurs in the tool. Since this amount of heat is not known, the inverse technique is adopted in which the heat transfer in the tool is adapted to numerical model until the temperature in remote locations inside the domain coincides with the experimental measurements.

2. Heat generation in tool surface

When wood is processed by knifes, the source of heat is the friction work done on the contact surfaces. Figure 1 illustrates a pressure distribution when the cutting tool is in contact with workpiece. Pressure distribution develops on the edge and front surface of the knife while the chip moves with v speed in relation to the knife. The theoretical value of the generated heat is [3]:

$$Q = v\int_F \mu\sigma . df \tag{1}$$

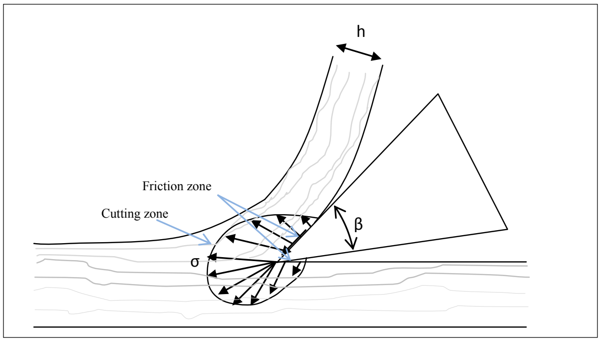

Fig 1. The stress distribution on the surface of the tool.

The theoretical value of the specific heat flow on the rake face can be written as follows:

$$q = \frac{1}{1,3}\mu B b v \psi \left(\frac{\varphi}{360}\right) \tag{2}$$

Taking into consideration the expression of the force acting on the edge, the theoretical value of the specific heat flux to the edge will be:

$$q = \mu\sigma_c b v \psi_1 \left(\frac{\varphi}{360}\right) \tag{3}$$

The comparison between the experimental measurements and theoretical values of the temperature inside the cutting tool has showed that only 60% of the theoretical values of frictional heat appear as effective heat on frictional surface.

Numerical-experimental research approach will be adopted in this paper in order to determine the temperature distribution over the whole geometry of the tool in continuous process of cutting wood. The aim of this approach is to provide a realistic amount of the cutting power passing into thermal energy, which occurs in the tool. Since this amount of heat is not known, a priori the inverse technique is adopted in which the heat transfer in the tool is adapted to numerical model until the moment when the temperature in remote locations on the domain boundaries coincide with the experimental measurements.

The temperature of the tool depends at the most on the peripheral speed, the thickness of the chip, the edge rounding radius and the sharpening angle.

Friction coefficient values were determined from cutting force measurements. The previous questions can be answered partly from experimental results and partly from theoretical considerations. If the boundary conditions; the location of the heat flow and intensity, heat transfer on the surface are known, then the differential equation of the heat conductivity can be solved with a computer by numerical simulations. In our case we use boundary element method and the whole temperature field can be determined.

The empirical equation describing the temperature can be written as follows [5]:

$$T = T_0 + (26.6\rho^{0.8} + 1053 \cdot x^{0.8})\frac{v^{0.8}}{\beta^{0.95}} \tag{4}$$

Some authors (Sitkei et al. [5]) have measured temperature at the bisector of the teeth at certain distance Δx from the peak. Making extrapolation of results at certain points with known results it is possible to get the temperature at the peak of the teeth. In figure 2, the results from experimental measurements of temperature at the bisector of the teeth are shown. Each curve represents measurement of temperature for different average feed per tooth in mm.

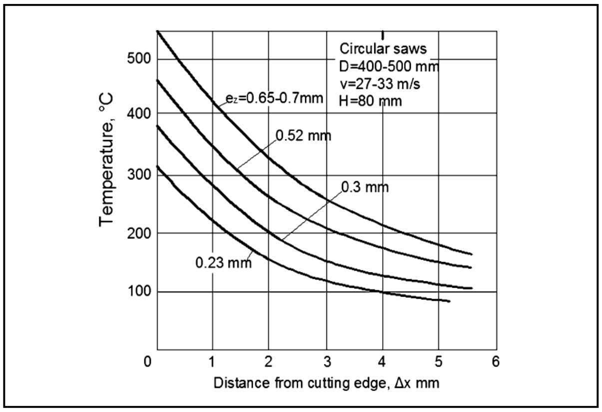

Fig 2. Variation of the temperature in the bisector of the edge working with different feed per tooth (Sitkei et al. [5]).

Many factors influence the temperature field in the tool. The geometric characteristics of the cutting tool, the heat conductivity of the tool's material and its specific heat influence the temperature. The true heat flow is smaller than the theoretical value both on the edge and on the rake face, because friction is an irreversible process. Furthermore, friction, as a shearing stress, generates deformations in both contacting materials, which also consumes energy and finally some heat will be dissipated into the air. The frictional heat is generated on the contact surface of the chip and the tool, so a smaller part of the heat flows into the chip and the greater part flows into the knife. A further possible inaccuracy may be given by the fact that the effective friction coefficient between the tool and wood cannot be measured during the cutting process.

3. Boundary element method BEM

Several numerical methods are available in the literature to solve thermal models and have been applied to solve thermal problems in cutting tools. In our study we have used the boundary element method BEM. Boundary element method has a lot of advantages [6], that we profit in our study:

- Under certain conditions, the resolution is faster than with finite element method
- For stationary calculations, the boundary element method can be faster for small models, but the assembly of full matrices becomes very long when a large number of nodes is considered.
- It is easy to get solution in every point anywhere inside the domain.

4. Boundary element method applied to the solution of Laplace's equation (stationary potential problem)

The boundary element method (BEM) popularized by Brebbia [7] can easily solve these problems. The method is based on:

- The heat equation as an integral equation on the boundary for any point of area and its border,
- The discretization of the boundary and the boundary integral equation,
- The resolution of the discrete boundary integral equation on the boundary,
- The resolution of the boundary integral equation inside the domain.

The details of the method applied to thermal or mechanical problems can be obtained in works of Brebbia [7] or París [8]. We will recall here the basics of the method applied to a stationary potential problem. As a first step, we consider only the boundary conditions; temperature and flux.

The starting boundary integral equation required by the method can be deduced in a simple way based on considerations of weighted residuals, Betti's reciprocal theorem, Green's third identity or fundamental principles such as virtual work. The advantage of using weighted residuals is its generality; it permits the extension of the method to solve more complex partial differential equations.

Consider that we are seeking to find the solution of a Laplace's equation in a Ω (two or three dimensional) domain.

The problem is therefore written in general by the following equation:

$$\forall M \in \Omega, \quad \vec{\nabla}^2 T(M) = 0 \tag{5}$$

with following boundary conditions:

$$\forall M \in \Gamma_T, \quad T(M) = T_0 \tag{6}$$

$$\forall M \in \Gamma_\phi, \quad -\lambda \vec{\nabla} T(M) \cdot \vec{n} = \phi_0 = -\lambda q_0 \tag{7}$$

Note $q = \vec{\nabla} T \cdot \vec{n}$, the temperature gradient in the outward normal (and $q^* = \vec{\nabla} T^* \cdot \vec{n}$).

5. Fundamental solution

The fundamental solution T* satisfies Laplace's equation and represents the field generated by a concentrated unit charge acting at a point 'i'. The effect of this charge is propagated from i to infinity without any consideration of boundary conditions. For an isotropic medium 2D, T* and q* are Green functions.

$$T^* = \frac{1}{2\pi}\ln\frac{1}{r} \quad \text{and} \quad q^* = \vec{\nabla}T^* \cdot \vec{n} = \frac{d}{2\pi r^2} \tag{8}$$

Where r is the distance from the point of collocation P to the point M of the considered border($r = \|\vec{r}\|$ and $\vec{r} = P\vec{M}$). "d" is the distance of the opposite projection of r on the outgoing normal M ($d = -\vec{r} \cdot \vec{n}$). The distances r and d are shown in figure 3.

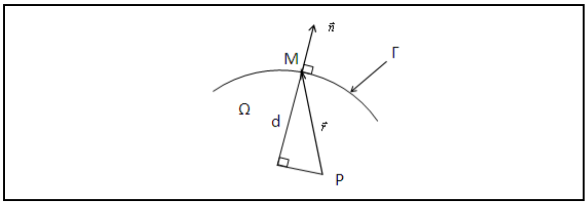

Fig. 3. Geometry definitions.

6. Boundary integral equation

Using the definition of the Dirac function δ_p we obtain the integral formulation on the boundary.

$$cT(P) + \int_\Gamma T(\vec{\nabla}T^* \cdot \vec{n})d\Gamma = \int_\Gamma T^*(\vec{\nabla}T \cdot \vec{n})d\Gamma \tag{9}$$

Applying the above equation to a collocation point i (or the boundary area), we have:

$$c_i T_i + \int_\Gamma Tq^* d\Gamma = \int_\Gamma qT^* d\Gamma \tag{10}$$

For a 2D problem, the calculation of integrals Γ of this equation is equivalent to a 1D integrals on the border. It is divided into elements which may be chosen from several types according to the degree of interpolation and continuity. In our simulations we have used the constant elements. The integral equation is initially applied to the nodes of the boundary, which allows to obtain solutions at these points. In a second step, the equation can be applied to points within domain called internal points.

If boundary integral equation is applied to the ''i'' collocation point located within the domain, the form c_i factor takes the value 1.

$$T_i = \int_\Gamma qT^* d\Gamma - \int_\Gamma Tq^* d\Gamma \tag{11}$$

7. Results and discussion

In our study we have taken a tooth of the cutting tool to figure out the temperature distribution in this type of tools. The sharpening angle β of the tooth in the first simulation is 45°. The clearance angle α is supposed to be 10-15°. Mesh of the tooth is shown in the figure 4 and takes only the contour of the geometry. In the domain of the geometry we have distributed the internal points that serve to calculate the solution inside the domain. It is distributed in the way to get more information in zones where we expect to obtain more data about temperatures. It means that we have taken very dense distribution of internal points near the peak of the tooth and very coarse distribution on farther zone. We have taken 28 constant elements, with finer mesh near the peak of the tooth. For our BEM calculations we have taken 9 or 18 internal points, such as previously explained.

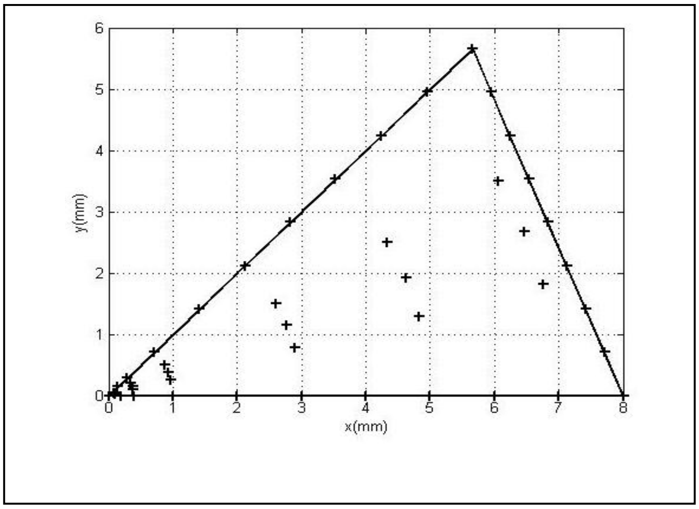

Fig. 4. Mesh of the contour of the tool (β=45°) with internal points.

At the start, for first simulation we were interested to get the temperatures along the bisector line taking 9 internal points and with imposed temperatures on cutting edges and temperature gradients on the back side. In the literature (see figure 2), the experimental results are available along bisector line for different feed per tooth. Our results in figure 5 show a good accordance with experimental ones.

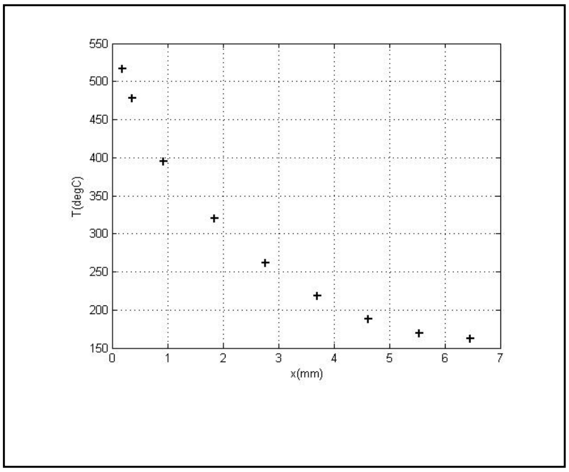

Fig. 5. Temperature on bisector line.

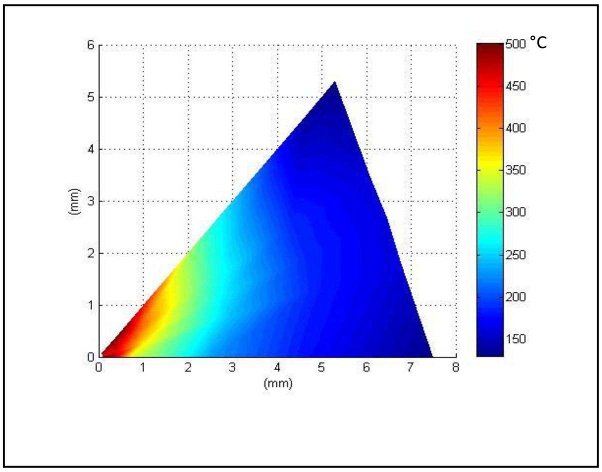

Fig. 6. Temperature distribution in the tool.

For the same boundary conditions, the temperature distribution inside the domain is represented in figure 6, taking 18 internal points. The maximum temperature is on the peak of the tooth. The temperature is decreasing along the lines from peak to the back of the tooth.

Next investigation is done on rotation speed of the tool.

Figure 7 and 8 represent the temperature distribution over the tool for rotation speeds 6000rpm and 4000rpm respectively. The high peripheral speed generates large frictional power and as a consequence, high surface and internal temperatures near the peak of the tooth.

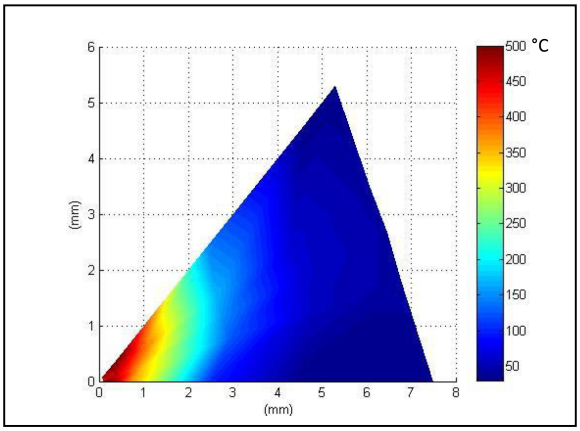

Fig. 7. Temperature distribution for rotation speed of the tool 6000rpm.

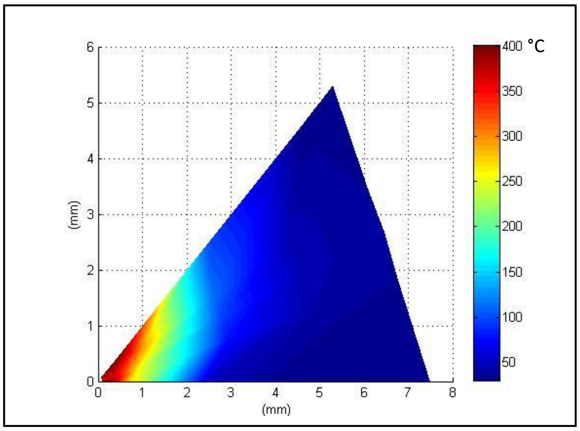

Fig. 8. Temperature distribution for rotation speed of the tool 4000rpm.

In the next instance we took the geometry of the cutting tool with sharpening angle 60°. The mesh is made in similar way, with finer mesh near the peak of the tool. The same is done with internal points.

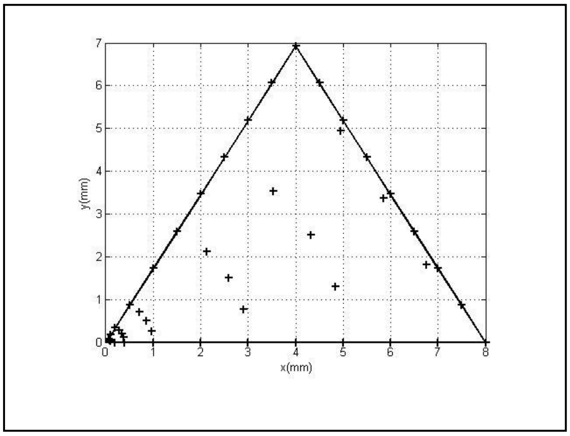

Fig. 9. Mesh of the contour of the tool (β=60°) with internal points.

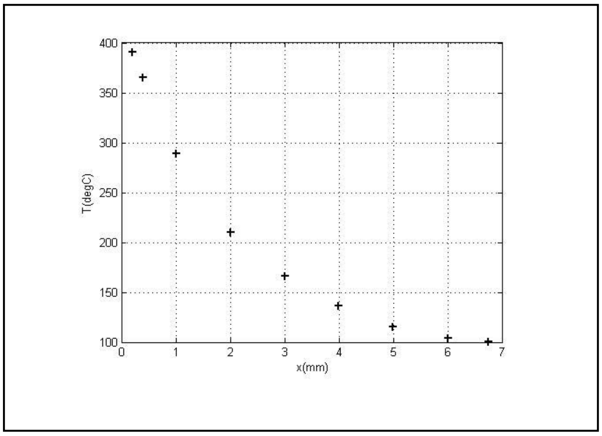

Fig. 10. Temperature on bisector line.

The numerical results are validated such as in previous instance in figure 9, comparing the results at the bisector line with experimental ones. The temperature distribution for this geometry is done over the whole domain. Here, we have investigated influence of the thickness of the chip on temperature distribution in figures 11 and 12.

Large thickness of the chip causes higher temperatures inside the domain, particularly near the peak of the tool. The temperature field on the rake face is greater than on bottom face.

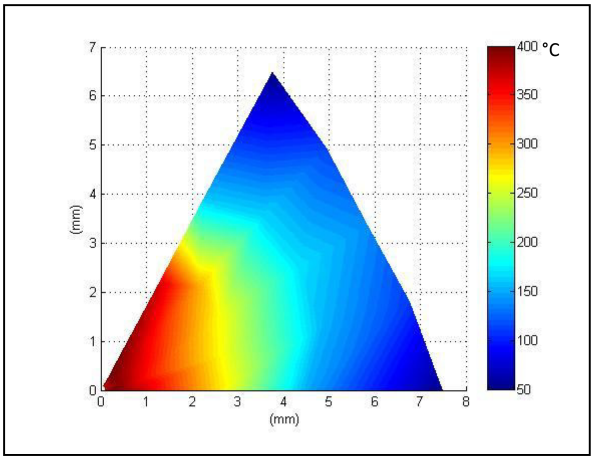

Fig . 11. Temperature distribution in the tool for e=0.52mm.

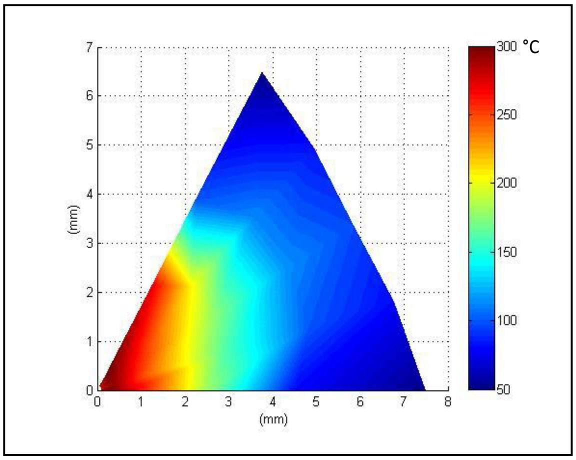

Fig. 12. Temperature distribution in the tool for e=0.25mm

8. Conclusion

It is difficult to measure the temperature on the surface of the tool, particularly near the peak. Knowing the experimental measurements inside the tool, it can be easy to get numerical solution of the temperature over the whole geometry of the tool. This inverse technique can be useful to get rapid solution of temperature distribution inside the domain and on the surface of the cutting tool. Boundary element method is very advantageous numerical method over other ones for simulations on simples geometries such as in our case; the tooth of the tool. By the boundary element method, it can be easily shown that the maximum temperatures occur at the peak zone. The temperature of the tool itself changes slowly and only slightly at 4–5 cm away from the edge surface. In this study we concentrate our effort to show the temperature distribution in the tool. It is known that the peaks of the tools are exposed to higher temperature fields what means that this region of the tool is susceptible to be the most worn. Finally, the tool wear, particularly on the peak of the tool, can be directly correlated to the temperature field and is one of the most important reasons to have irregularities on production process.

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