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INVESTIGATION ON CUTTING TEMPERATURE AND TOOL-WEAR AND COMPARING THEM WITH FEM RESULTS

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ABSTRACT
Finite element modeling (FEM) of machining is a widely applied way to get information about the phenomena occurring during the cutting process. However, the results have to be validated by real data collected by cutting experiments. We have realized a machining experiment focusing on temperature and tool-wear. The paper introduces some results and compares them with the FEM outcomes.

Keywords: FEM, cutting temperature, tool-wear

1. INTRODUCTION
The increasing customer needs for higher quality enlarge the significance of precision machining. It is a relatively new area of machine industry and requires intensive experimental and practical investigation activity referring to technological parameters and circumstances. One part of the research activity of our department is the scope of precision machining and the applicability of our results in the industry. The monitoring of cutting processes predestinates the investigation on the major technological variables determining the shape and dimensional accuracy of the machined parts. Among several influences cutting temperature plays an important role in metal cutting. In the next chapters the correlation between temperatures occurring during cutting process and tool wear will be introduced. Certain temperature measuring systems could be suitable for monitoring the cutting process. It has a major importance especially in CNC machining.
The shear plane temperature is of importance for its influence on flow stress and since it has a major influence on temperatures on the tool face and on the relief surface. The latter two temperatures are very important to crater wear rate and rate of wear-land development respectively. The temperature on the tool face also plays a major role relative to the size and stability of the built-up edge. [1]

2. METHODS OF TEMPERATURE MEASURING
There are a lot of methods to measure temperature during machining. The earliest method uses calorimeter which measures the average temperature of the chip indirectly. It is not an efficient solution because it does not give an exact result referring to the cutting temperature. In connection with the commonly used techniques, it is another conceptual problem: the definition of cutting temperature. It is no matter that we define it as a maximal or as an average temperature value in the environment of cutting edge. The first approach requires such a method that detects temperature only in one point.
The most extensively used method is the tool-work thermocouple. This method is useful in showing the effect of cutting conditions, such as cutting speed and feed rate, but the absolute values are inaccurate. Another method used to measure the temperature and gradients in the tool is that of inserted thermocouples. Using thermocouples of small diameter, it is possible to obtain good results in relation to the temperature gradients in the tool by means of many small holes in different positions.

The technique of measuring temperature by the measurement of radiation is sometimes very useful in obtaining the surface temperature of the workpiece, the chip and the tool [2]. Numerous paper detail results of experiments performed with using infrared camera [3, 4] and optic fibre method [5, 6]. A more complicated method is measuring with built-in thin film thermocouple sensors [7] but it works very well in monitoring the temperature.

3. PROCEDURE AND CONDITIONS OF INVESTIGATION

On the Kecskemét College, Department of Manufacturing Engineering optic fibre method were carried out to measure cutting temperature. Figure 1 shows the layout and the structure of the measurement. The workpiece was held in three-jaw chuck of the turret lathe. The temperatures were detected besides different tool-wear values. In case of optic fibre measuring the fibre was positioned near the heat source and the infrared radiation was transmitted to a sensible diode and the analogue voltage signals induced by the heat was transmitted to a computer through a digital voltameter and an A/D converter [6]. Later we repeated the experiment with the same technological parameters, machine and tool. But the temperature measurement was carried out with infrared camera (FLIR T360). To use a technique which detects infrared radiation we have to consider several enviromental variables. In case of IR camera the next important parameters had to be measured before data collection: specific emission, reflected temperature, temperature of enviroment, specific humidity and distance between the chip and measuring device. Table 1 includes the major parameters referring to the technology, workpiece, and tool.

Table 1. Technical data of the experiments

Workpiece	Dimension	Ø168×600 mm
	Material	X6CrNiTi 18-10 (austenitic steel)
Tool	Insert	SNMM 120408FN
	Cutting tool	PSBNR 2525 M12
	Material	P20 tungsten carbide
	Coating material	titan carbide
	Rake angle	γ = -6°
	Relief angle	α = +6°
Technological conditions	Cutting speed	v_c = 147 m/min
	Feed	f = 0.25 mm/rev
	Depth of cut	a_p = 1 mm
	Coolant	Dry cutting

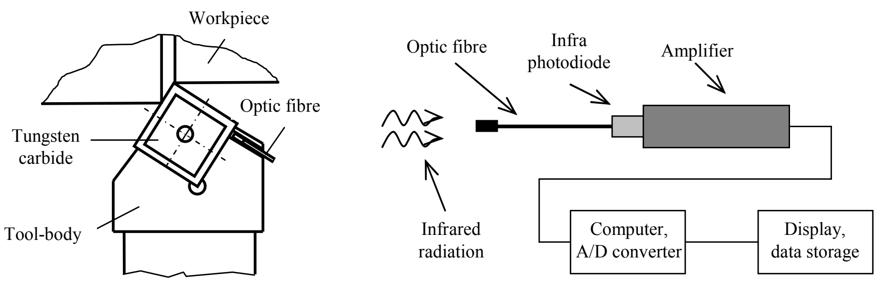


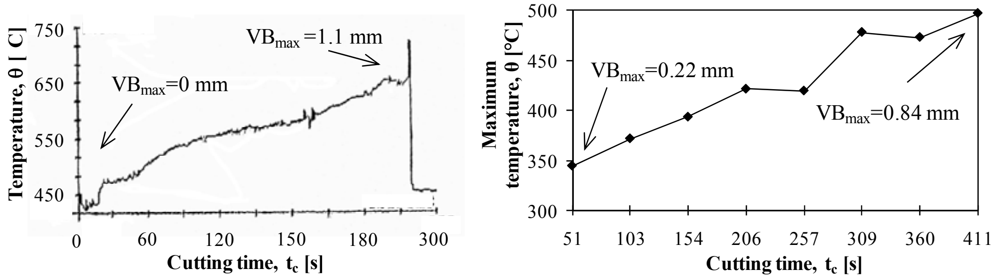
Figure 1. Layout and structure of the temperature measurement (optic fibre method) [6]

Finite element modeling of machining could give some information about several parameters of cutting process. It is used for simulating the machining with defined cutting edge [8, 9], but applicable for simulation of abrasive machining too [10].

To get information about the applicability of finite element modeling systems some cutting simulations were carried out by using the Third Wave Systems' AdvantEdge software V5.6-014. It ensures the two and three dimensional simulation of turning. All the technical data referring to machining were the same as in the real experiments but some limitations were built in. In case of 2D FEM, the software simulates orthogonal cutting, which influences the active angles. Furthermore it is easy to define special tool geometry but modeling of real wear land is impossible.

4. RESULTS OF THE EXPERIMENTS AND THE FINITE ELEMENT MODELING

The results of temperature measuring methods based on infrared radiation are shown on figure 2a and 2b. The diagrams are similar and show the typical tendency referring to correlation between temperature and tool-wear. During the experiments we collected more data, and measurement results had validated the earlier results get by optic fibre method.



a.) b.)

Figure 2. Measured temperatures by optic fibre method (a) and infrared camera (b)

In the first investigation measurement was realized by continuous cutting. To fulfill the task of comparing the trend of tool-wear and temperature, Kodácsy [6] performed short-time machining experiments by inserts that showed different dimensions referring to VB tool-wear. After 2-5 seconds the temperature diagram became constant and these values showed strong correlation to data collected later by IR-camera measuring. The recorded function describing connection between tool-wear and temperature was especially logarithmic, which agrees with experts' results publicated in literature.

Finite element modeling gives information about the cutting process but the most important rule of using it is the fact that the results are inacceptable without validation by real experiments. To investigate how effective FEM is, I performed some simulation. Considering the limitations of the used software all possible input parameters were the same as in real experiments. Figure 3 demonstrates the results of the 2D standard simulation. The equation (1) and (2) and the diagram confirm that 2D FEM model is not enough to get reliable information about the lightened issue because the outcomes are far from the real experiment results, where the difference in temperatures caused by tool-wear is about 200-250°C. The functions fitted to the measured temperature values are agree with theoretical establishments.

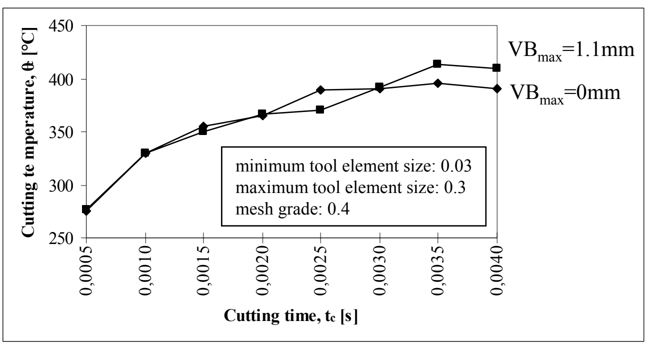


Figure 3. FEM results of cutting temperatures besides different tool-wears

$$\theta_{0,0} = 285 + 58 \cdot \ln t_c \text{; } (R^2=0.958) \quad (1)$$

$$\theta_{1,1} = 279 + 64 \cdot \ln t_c \text{; } (R^2=0.979) \quad (2)$$

I performed a 2D simulation in rapid mode besides different tool-wear values to get the temperature data. Differences between two VB_{max} dimensions of wear land were about 0,2 mm. Unfortunately the results were the same in all version. However using 3D standard modeling, the temperature values are quite elegant (Figure 4). On the one hand, the diagram shows the typical feature of temperature function: after fast increasing (enormous friction between tool and workpiece) comes an uncertain phase, when the cutting wedge enters the material. On the other, the next phase (degressive) begins earlier than expected.

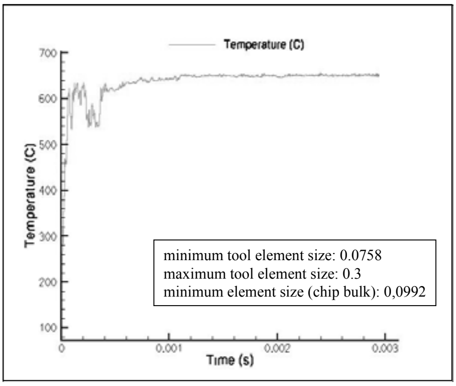


Figure 4. Cutting temperature by standard 3D finite element modeling

5. CONCLUSIONS

A finite element modeling software specialized to metal cutting are not able to give exact results referring to the correlation between tool-wear and temperature. Simulation in 2D rapid mode gives the same data for maximum cutting temperature if tool geometry changes. 2D standard mode gives better values but it does not reflect the circumstances of the real experiment. Accordingly, our expectations stay far from the results. 3D standard modeling follows the real machining environment on the most satisfactory way but we must not forget that finite element modeling does not substitute the real experiments, especially if we perform dynamic investigations, id est effects of changing variable to another one. Circumstances of precision machining are different from the introduced investigation. Therefore several results are special, e.g. white layer formation, wear mechanism etc. Further investigations have to be focused on these atypical mechanisms besides precision machining.

6. ACKNOWLEDGEMENT

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