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Analysis of Temperature in Metal Cutting and Its Measurement Methods

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Abstract: In this paper, traditional and novel technologies of measuring the heat generated in metal cutting process are studied. Analysing the literature about the cutting temperature, conclusions on the influence of temperature in metal cutting zone are given. Moreover, popular methods of measuring the temperature while conducting a machining process are presented, and their advantages, limitations are discussed. The paper is prepared using reviews of the literatures.

Keywords: Cutting parameters, metal cutting, measurement, thermocouple, temperature.

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1. Introduction

Machining is one of the most common manufacturing processes, and metals and alloys are the main materials used in this process. Therefore, the field of metal cutting has been the focus of attention of many researchers, and many scientific works have been created. Since the beginning of mechanical processing of such materials, many problems have appeared and many solutions and ideas have been proposed. Great progress has been made in increasing metal cutting speed and reducing costs [1, 2]. Increasing metal cutting speed means more material can be cut in less time, and this is achieved by increasing cutting speed, feed and depth of cut. Doing this cost-effectively depends on many aspects of metal cutting, such as the machine tool, the cutting tool, the lubricant, the coolant, and the materials. It is necessary to increase strength and accuracy in metal cutting machines. Some cutting tool materials are brittle, such as ceramics, and such tools should be used on high-precision machines [3, 5]. An increase in power to remove more material in a shorter time increases heat generation on the cutting-edge side of the tool, and the power required to cut metal is mostly converted to heat. This heat is released by four systems that process the material: the cutting tool, the processed raw material, the resulting chip and the lubricating coolant (LC) [6].

Since temperature has got fundamental importance in metal cutting operations, many attempts have been made to determine (measure, control) it [7, 8]. Some work simply uses the relationship between the work done and the volume of metal involved in the process to get the average temperature. Others use computers to help with temperature distribution. Methods of measuring temperature in metal cutting are not very developed, so it is difficult to prove theoretical results. In this work, a qualitative comparison is made between some experimental results obtained by several methods available in the extensive literature on this topic and some results obtained using a theoretical method.

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Literature Review

A number of scientists have conducted experimental research and scientific research in this regard and have achieved different results. Their experiences will be considered below.

L.B. Abhang [9] worked on the prediction of the temperature at the cutting tool interface during the turning process. In this study, cutting speed, thrust, depth of cut, and tool tip radius were taken as metal cutting parameters. It can be seen that cutting speed, feed and depth of cut are the parameters that have the most important effect on the temperature of the chip-tool interface, followed by the radius of the tool tip. The results show that increasing the selected cutting parameters increases the cutting temperature, while increasing the tip radius decreases the cutting temperature.

The basis for estimating the generation of heat due to mechanical processing was laid by Rumford and further strengthened by Joule's finding of the mechanical equivalent of heat. Although its use in metal cutting was first reported by Taylor, since then scientists and researchers have developed various methods to estimate temperature changes at different points in the tool, cuttings and raw materials. These methods can be divided into three broad categories: experimental, analytical, and finite element analysis. Each has its own advantages and disadvantages [10].

M. Cotterell and others [11] worked on measuring temperature and deformation in the process of chip formation under orthogonal cutting conditions. The temperature and normal stress generated at the tool-chip interface are important parameters for tool wear and raw material damage. The main effect of temperature is on the device. Although there are various mechanisms of tool wear, it is generally known that an increase in temperature leads to progressive wear of the tool. In addition to the tool, the maximum temperature and the temperature gradient affect the surface deformation, the structural changes of the metal on the machined surface, and the residual stresses. A more pressing problem arises when cutting materials with low thermal conductivity, such as titanium, where the heat generated during the cutting process flows much more in the tool than in the chip due to the low thermal conductivity of the raw material being processed, and in this tool thermal causes tension. As a result of temperature stresses, failures due to fatigue, wear and loss of the cutting tool occur more often.

Bogdan P. Nedik et al. [12] worked on cutting temperature measurement and material handling ability. Cutting temperature is a very important parameter of the cutting process. About 90 percent of the heat generated during the cutting process is transferred to the chip, and the rest to the cutting tool and raw material. In their study, they measured the cutting temperature using an artificial thermocouple and analysed the machinability of the metal in terms of the cutting temperature. To test the machinability of the material during turning, the artificial thermocouple was placed slightly below the cutting surface of the cutting plate, and the thermocouples for drilling were placed through the screw grooves on the front surface. Using these methods, they obtained a simple, reliable, economical and accurate method of checking machinability during cutting.

Effect of cutting temperature on machining

The thermal phenomena that occur in the narrow and wide area of the cutting zone are directly related to the tool wear rate, the processing ability of the machined material, the stability of the tool, and many other characteristics of the machining process [13-15]. Experimental studies show that almost all the work of cutting forces is converted into heat energy. The generated heat passes from the cutting zone to the chip, the tool, the cutting edge and the environment, causing a decrease in the hardness of the cutting elements of the tool, cutting deformation, the loss of the cutting ability of the tool and its failure. The distribution of heat generated in workpiece, tool and chips, that is, the temperature level in the working elements of the tool on the processed surface and chips, depends on the following: material of the blank (its mechanical and chemical properties), cutting speed, feed, depth of cut, tool geometry, lubricating-cooling fluids and other relevant parameters [16-18].

In addition to affecting tool wear, the heat generated during cutting affects the productivity of the machining process, the quality of the machined surface, the accuracy of machining, and other output parameters of the machining process. Therefore, it is very important to check, measure and know the levels and distributions of the cutting temperature in the tool and the workpiece. Based on this knowledge, optimal conditions, cutting modes, process quality, productivity and economy, and tool life can be determined [19, 20].

Methods of cutting temperature measurement

In experimental works, many methods have been used to determine the temperature distribution in the cutting area, as new technologies have been developed in the tool industry. The nature of machining conditions, materials and products of new cutting tools, such as small sizes, high speeds and large temperature gradients, have made experimental work difficult to develop specific tools for precise temperature measurement in the cutting area. Commonly used methods for temperature measurement include: instrument pair or embedded thermocouple (Fig. 1), infrared radiation, thermosensitive staining or microhardness change metallographic, colour temperature, and thermal camera. Each technique has its advantages and limitations depending on the physical phenomena used for measurement [21-23]. New efforts are underway to provide accurate measurements of the temperature field in the shear zone. The experiments provide a thermal map of the shear zone and supporting data for all analytical and numerical work.

Decreasing the share of the heat passing to the detail when the cutting speed increases occurs as a result of the change in the ratio between the speed of heat spreading from the deformation zone and the cutting speed. The amount of temperature in the cutting zone is affected by the following factors: physical and mechanical properties of the processed material, cutting modes (cutting speed, feed and depth of cut), geometric parameters of the cutting tool and the used lubrication-cooling technological environment. Despite the fact that significant progress has been made in the application of analytical methods in the study of thermal phenomena in the area of deformation and on the contact surface of the tool, experimental methods remain the main method of research due to their simplicity and reliability. The following main methods of temperature determination are used in the experiment: calorimetric, comparative analysis of the colour change of the surface and treated surface, thermal paint method, optical pyrometry methods, various options of the thermoelectric emission method. The calorimetric method is based on measuring the temperature of falling slag using a calorimeter. This method makes it possible to determine the amount of heat transferred to the slag, detail and tool, as well as the average temperature of the chip. Determining the average temperature of slag by changing its colour is quite subjective, and significant errors can be made [21, 22].

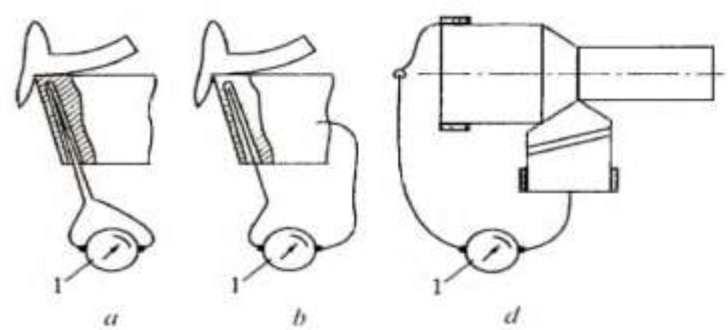

Figure 1. Thermocouple schemes: a - artifical; b - semi-artificial; d - natural; l – Thermal electromotive force measurement tool.

The thermo-paint method is used to determine the surface temperature of the heated parts of the tool and is simple, visual, but not very accurate. Various thermocouple methods are widely used to measure the temperature on the contact surfaces of the cutting tool and at different points of the contact surface. The artificial thermocouple method is based on measuring the cutting temperature around the cutting edge using a chromel-alumel or chromel-copel thermoparallel (Fig. 1, a). A hole with a diameter of 1...2 mm is drilled in the cutter from its lower base towards the rake surface. The hole does not reach the surface by 0.2...0.4 mm. A thermocouple is placed in the hole. By placing the hole at different points along the front and back surfaces of the cutting edge, it is possible to get an idea of the temperature field on the cutting edge of the tool. In the semi-artificial thermocouple method (Fig. 1, b), one insulated conductor is brought to the investigated surface of the cutting edge, and the tool itself (body) is considered as the second conductor. In the natural thermocouple method, the tool and workpiece itself are conductors, the junction of thermocouple is the contact surface of the front and rear surfaces of the cutting edge (Fig. 1, d).

During machining, the tool and the workpiece change their position relative to each other, and therefore it is necessary to use specially designed collector to transfer the thermal EMF to the stationary recording devices 1. The spark plug insulation shown in Fig. 1(d) is necessary to eliminate the effect of parasitic thermocouples, but the role of parasitic thermocouples is not great when the temperature of the instrument contact surfaces is high, and at the expense of slightly reducing the measurement accuracy, by abandoning the spark plug insulation, the sharp the device can be simplified while keeping its insulation. In order to transfer the readings of the recording device to degrees Celsius, the thermocouple must be calibrated beforehand in a special way [24, 25]. Optical pyrometry methods allow to create an idea about the distribution of heat in the cutting area by recording its heat distribution. These methods involve the use of complex optical devices or photoelectric sensors. Determining the nature of the temperature distribution or the temperature field in the cutter and the material being processed is carried out by calculating exposure and thermal phenomena using electrical modelling based on the theory of heat exchange in solid bodies. It was possible to construct the temperature fields due to the use of the method of heat sources, which allows finding optimal engineering solutions with relatively simple mathematical methods. The essence of this method is that the temperature field that appears in a heat-conducting body under the influence of a heat source of any shape, motion, or static, temporary or continuous operation, and the temperature field that occurs due to the effect of a system of instantaneous point sources or can be formed as a result of a combination of these.

CONCLUSION

The temperature of the chip-tool interface is closely related to the cutting speed. As the cutting speed increases, friction increases, which leads to an increase in temperature in the cutting zone. As the speed of friction increases, the cross-section of the chip increases and, as a result, friction increases, which includes an increase in temperature.

The greater the work involved in cutting, the higher the cutting temperature, other things being equal. As the hardness and strength of the processed material increases, the cutting temperature increases. The thermal conductivity and heat capacity of the processed material also have a great effect. The higher the thermal conductivity of the material being processed, the higher the speed of heat transfer to the chip and workpiece, which means that the cutter heats up less. The amount of heat received by chip and workpiece depends on the heat capacity of the material being processed.

There many methods of measuring and controlling the heat generated in cutting zone, including instrument pair or embedded thermocouple, infrared radiation, thermosensitive staining or microhardness change metallographic, colour temperature, and thermal camera. Those methods have their own advantages and limitations according to the condition they are utilized.

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