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DETERMINING THE EMISSIVITY AT THE TOOL-CHIP INTERFACE DURING S235JR STEEL TURNING

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Abstract

Temperature on the chip-tool interface is important parameters in the analysis and control of turning process. Due to the high shear and friction, energies dissipated during a machining operation the temperature in the primary and secondary shear zones are usually very high; hence, affect the shear deformation and tool wear. In a single point cutting, heat is generated at three different zones i.e. primary shear zone, chip tool interface and the tool-workpiece interface. The primary shear zone temperature affects the mechanical properties of the work piece – chip material and temperatures at tool-chip and tool-work piece interfaces influence tool wear at tool face and flank respectively. Total tool wear rate and crater wear on the rake face are strongly influenced by the temperature at chip-tool interface. Therefore, it is desirable to determine the temperatures of the tool and chip interface to analyse or control the process.

To measure the temperature at the tool-chip interface many experimental methods have been developed over the past century. Since at the interface there is a moving contact between the tool and chip in this work, authors propose infrared method for temperature measuring. To assure possibly high accurate of noncontact temperature measurement there is a need to keep in mind several factors, including determining appropriate value of emissivity. In this work, authors present results of experimental determining emissivity value of tool-chip interface. As initial value, emissivity of polished steel was taken.

Keywords: *turning, infrared measurement, tool-chip interface temperature, emissivity*

1. Introduction

Temperature is the most frequently measured physical quantity, second only to time. Temperature plays an important role as an indicator of the condition of a product or piece of machinery, both in manufacturing and in quality control. Accurate temperature monitoring improves product quality and increases productivity. Downtimes are decreased, since the manufacturing processes can proceed without interruption and under optimal conditions.

Infrared technology is not a new phenomenon – it has been utilized successfully in industrial and research settings for decades – but innovations have reduced costs, increased reliability, and resulted in noncontact infrared sensors offering smaller units of measurement [7, 9, 10].

The advantages offered by noncontact temperature measurement are:

1. It is fast (in the ms range) – time is saved, allowing for more measurements and accumulation of data (determination of temperature field).
2. It facilitates measurement of moving targets (conveyor processes).
3. Measurements can be taken of hazardous or physically inaccessible objects (high-voltage parts, great measurement distance).
4. Measurements of high temperatures (greater than 1300°C) present no problems. In similar cases, contact thermometers cannot be used, or have a limited life.
5. There is no interference – no energy is lost from the target. For example, in the case of a poor heat conductor such as plastic or wood, measurements are extremely accurate with no distortion of measured values, as compared to measurements with contact thermometers.

6. There is no risk of contamination and no mechanical effect on the surface of the object; thus wear-free. Lacquered surfaces, for example, are not scratched and soft surfaces can also be measured.

All of these factors have led infrared technology to become an area of interest for new kinds of applications and users, including lapping process observations [7, 9, 10].

2. Turning temperature

Turning is one of the most common of metal cutting operations that produces cylindrical parts. In turning, a workpiece is rotated about its axis as cutting tools are fed into it, shearing away-unwanted material and creating the desired part. Particles of material, the chips, are removed by cutting edge of a tool. The tool has one cutting edge, which is geometrically defined by number, shape, and position [3, 4, 8].

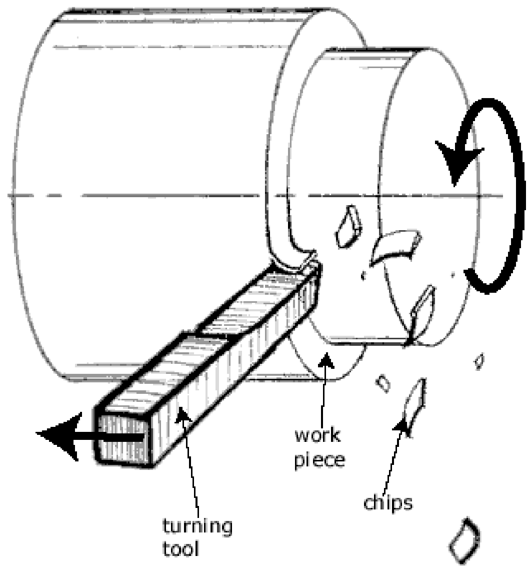

Fig. 1. Turning process fundamentals [4]

In turning chips are formed by a shearing process (Fig. 2). Most of the energy required to form the chips is converted into heat. There are three main sources of heat when cutting, as depicted in Fig. 2:

1. plastic deformation of the work piece surface,
2. the friction of the chip on the tool cutting face,
3. the friction between the tool and the work piece on the tool flank [1, 5].

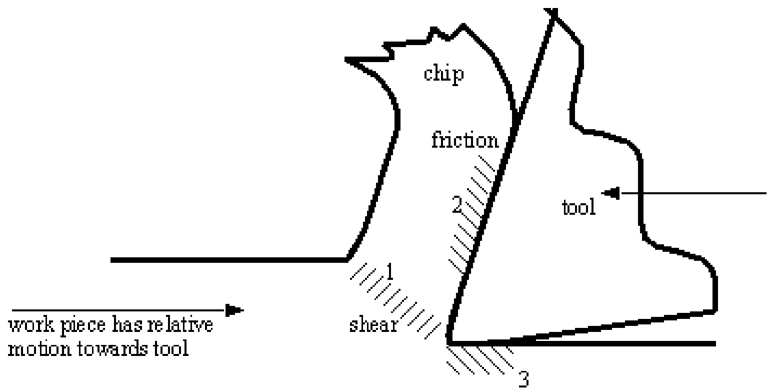

Fig. 2. Chip formation process during turning [5]

The temperature in the cutting zone depends then on contact length between tool and chip, cutting forces and friction between tool and work piece material. Its distribution depends on the heat conductivity and specific heat capacity of the tool and the work piece and finally the amount of heat loss based on radiation and convection [1, 2, 5].

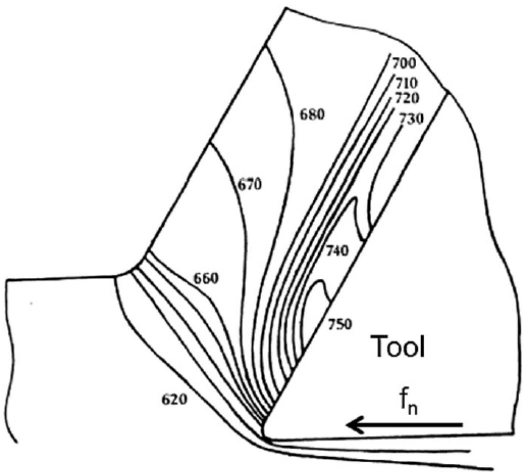

Fig. 3. Typical temperature distribution in the cutting zone (in °C) [2]

As shown in Fig. 3. the maximum temperatures occur in the contact zone between the chip and the tool. The heat is shared by the chip, cutting tool, and the work piece. Studies have shown that maximum amount of heat is carried away by the flowing chip (Fig. 4). From 10 to 20% of the total heat goes into the tool and some heat is absorbed in the work piece [1, 5, 12].

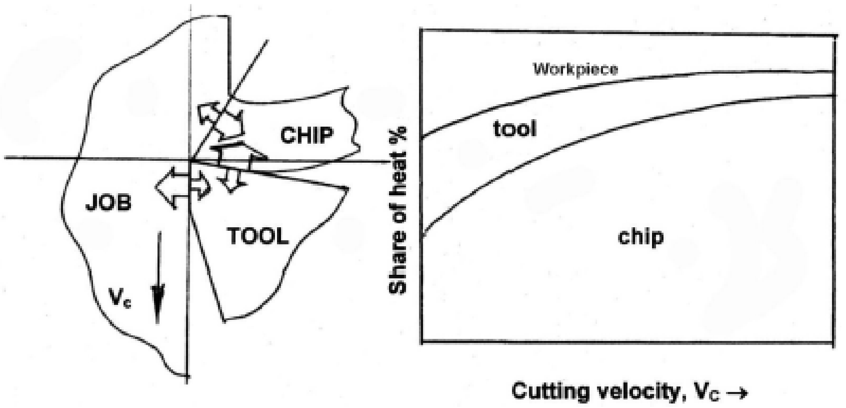

Fig. 4. Typical temperature distribution in the cutting zone (in °C) [12]

However, this small quantity of heat conducted into the tool and into the work piece is enough to create high temperatures. The effect of cutting temperature, particularly when it is high, is mostly detrimental to both. The possible detrimental effects of high temperature on cutting tool (edges) are:

- rapid tool wear, which reduces tool life,
- plastic deformation of the cutting edges if the tool material is not enough hot-hard and hot-strong,
- thermal flaking and fracturing of the cutting edges due to thermal shocks,
- built-up-edge formation.

The possible detrimental effects of cutting temperature on the work piece are:

- dimensional inaccuracy of the work piece due to thermal distortion and expansion contraction during and after cutting,

– surface damage by oxidation, rapid corrosion, burning etc.,
– induction of tensile residual stresses and micro cracks at the surface/subsurface.

Summing on, in turning, the heat generated on the tool is important for the performance of the tool and quality of the work piece. Hence, temperatures generated in the cutting zone are an important factor to take into consideration. The machining can be improved by the knowledge of temperature at the tool-chip interface [1, 12].

3. Methods of turning temperature measurements

Determination of the exact temperature rise in tool-chip interface is an important factor in achieving the best cutting performance. Many of temperature measurement techniques have been developed over the years to determine the temperature distribution of the tool-chip interface, rake face, cutting tool, work piece, chip surface, etc. The methods commonly adopted by the researchers are the metallographic method, i.e., micro hardness and microstructure analysis, calorimetric method, infrared photographic technique, thermo- sensitive paints, powders of constant melting point, thermocouple techniques. However, direct measurements of temperatures at the toll-chip-work piece interfaces are very difficult due to the cutting movement and the small contact areas involved. Because of these experimental difficulties, many analytical and numerical methods have been employed to predict machining temperature: the moving heat source method, the image sources method, the finite difference method, the semi-analytical methods and the finite element method [1, 2, 6, 11, 12].

Popular method among researchers is thermocouple method. It is very useful to indicate the effects of the cutting speed, feed rate, and depth of cut on the temperature. Thermocouples are conductive, rugged and inexpensive and can operate over a wide temperature range.

In this work, authors propose noncontact infrared methods for determining temperature and its distribution in tool-chip contact area. This was mainly due to thermography ability to catching moving targets in real time, to measure temperatures over some area not only in point. As a result of measurement, it is obtained a data set that is presented in a form of a colourful map: a thermogram. Because getting an accurate temperature of an object using this method is difficult, during experiments temperature rise can be analysed [1, 2, 12].

For measuring the temperature, infrared camera ThermoGear G100 produced by NEC Avio Infrared Technologies Co., Ltd. was used. The camera has two measuring ranges defined: -40 – 120 and 0-500°C. The measurement accuracy is ±2°C or 2% of reading, whichever is greater. The thermogram consists of 76800 measuring points (320 points in 240 lines). The image capture support functions of a 2-megapixel visible camera. Images that have been made can be presented as thermal, visible, parallel or as a mix of both (Fig. 5) [10].

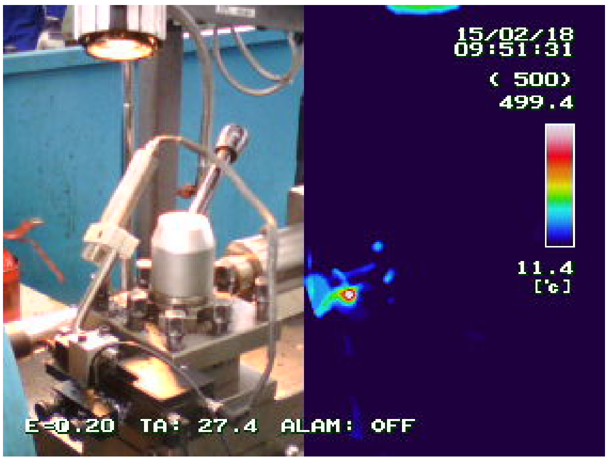

Fig. 5. Visible and thermal image of cutting area made during turning of S235JR steel

To analyse the results, computer software InfReC Analyzer NS9500 Lite generate Excel file report with temperature value for each point. An exemplary thermogram is depicted in Fig. 5.

4. Determining the emissivity of steel

To assure accurate noncontact infrared temperature measurement there is a need to keep in mind several factors, including determining appropriate value of emissivity. The last can be done in various ways.

First, emissivity of many frequently used materials can be found in a table. Particularly in the case of metals, the values in such tables should only be used for orientation purposes since the condition of the surface (e.g. polished, oxidized or scaled) can influence emissivity more than the various materials themselves. The emissivity of a particular material can be determined during experiment by different methods [7, 9, 10, 11].

Method chosen by authors involved heating up by cutting to a known temperature, measured with use of noncontact thermometer, and then measuring the target temperature with the infrared camera. The next step was changing the emissivity until the temperature corresponds to that of the thermometer. Emissivity value determined this way would be use for all future measurements.

5. Test procedure and results

Experiments were carried out on a conventional lathe CDS 6250 BX-1000 without using any coolant. A commercially available turning insert CCMT 09T304 – PF were used. The machining was performed using work piece of S235JR steel (250 mm long and 40 mm diameter). Turning parameters were as follow: feed rate f = 0.114 mm/rev, cutting speed v_c = 166 m/min, depth of cut a_p = 1.2 mm.

Finding emissivity of the work piece material required applying other thermometer next to the camera. For these purpose, noncontact temperature measuring device, integrated in DKM 2010 dynamometer (Fig. 6) was utilised. The maximum value of temperature in cutting zone was analysed.

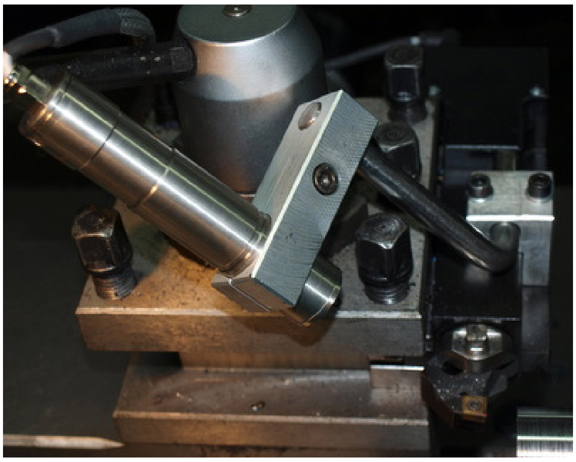

Fig. 6. Turning dynamometer DKM 2010[8]

Emissivity value strongly depends on temperature and surface finish. As initial emissivity of S235JR, steel was taken. According to Tab. 1, polished steel emissivity in 538°C is about 0.14.

Experimentally determined emissivity value for tool-chip interface was equal 0.20 and was bigger than value from the table. It may be caused by taken the initial value for work piece material since the maximum value of temperature is expected to be at the tool-chip interface. In further research, determined value can be taken.

Tab. 1. Emissivity values for steel [7]

Material	Emissivity values
Steel	
Cold-rolled	0.75-0.85
Ground sheet	0.4-0.6
Polished sheet	0.1-0.14 (38-538°C)
Oxidized	0.7-0.9
Stainless	0.1-0.8

6. Conclusions

The heat generated during metal turning processes affects materials properties and the tool wear. Knowledge of the ways in which the cutting conditions effect the temperature distribution is essential for the study of thermal effects on tool life. To execute such research, temperature at the tool-chip interface must be measured. Since at the interface there is a moving contact between the tool and chip in this work, authors propose infrared method for temperature measuring.

The most important thing about taking temperature measurements by infrared camera is to know the investigated element emissivity. There are emissivity tables of many frequently used materials but particularly in the case of metals, the values in such tables should only be used for orientation purposes since the condition of the surface can influence emissivity more than the various materials themselves. The emissivity of a particular material can be determined during experiment. Tool-chip interface emissivity obtained during experiment was 0.2. Designated value will be used in future research.

Because getting an accurate temperature of an object using this method is difficult, during further experiments temperature rise can be analysed.

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