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'In-situ' temperature measurement to determine the machining potential of different tool coatings

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Abstract

Measuring techniques for various machining operations were developed by DaimlerChrysler. These measuring techniques are based on the projection of the infrared radiation from the tool chip interface onto the scanner of a high resolution thermographic camera. In that way, it is possible to determine the absolute temperature and its distribution in the contact zone between the tool and the chip flow 'in-situ', whilst avoiding real time mechanical contact.

Keywords: Dry machining; Tool coatings; Temperature

1. Introduction

During the last decade dry machining has achieved increasing importance in series production due to the associated cost reduction and compliance with stricter environmental legislation. The cutting tools for dry machining are highly strained by various tribological stresses caused by mechanical and tribochemical factors. Studies have been undertaken to optimise the cutting substrate, the tool cutting geometry and the tool coating. The effort of dry lubricant coatings is the reduction of friction between the component material and the tool's surface. The diminished friction induces a reduction of frictional heat. With decreasing temperature, tool life increases.

In this regard, a BMBF—Project was initiated in 1998 that sought to develop dry lubricant coatings for cutting and forming tools. During this project, there was a requirement to generate devices capable of 'in-situ' temperature measurement. These devices utilise a high resolution thermographic camera during the different machining operations, thus making it possible to accumulate knowledge about the temperatures generated during the process and to compare the characteristics of different coatings with one another. For recording the temperatures of the tool and the workpiece, the heat radiation emitted is determined contact-free by using a thermographic camera. All described temperature measurements were carried out with the Thermovision 900 system produced by Agema Incorporation. In a measuring range from −30 °C to +2000 °C the maximum recording frequency obtainable is up to 30 Hz in the image recording mode and up to 2500 Hz in the line scanning mode. The following chapters describe in detail the development of the thermographic measurement and the experimental set-ups for the drilling operation. Additional examples of selected results are given.

2. Development of the thermographic measurement

The technique of the 'in-situ' measurement during a dry turning process was originally developed in 1993 at the DaimlerChrysler Research Centre, Ulm [1,2]. The intention was to examine the quantitative temperature distribution and the corresponding wear behaviour of diamond coated tool inserts during dry machining. The system utilises the infrared transmissivity of these coatings. The measuring technique has been further developed in order to determine the temperature behaviour of non-infrared transparent coatings. The impulse for this was given in the BMBF project on new dry lubricant tool coatings.

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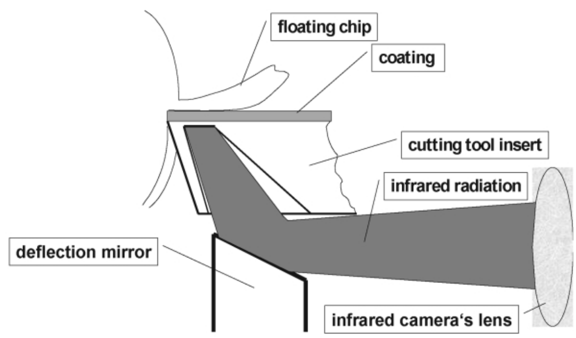

Fig. 1. Modified experimental set-up for the 'in-situ' temperature measurement during dry turning [4].

The currently evolution of the used set-up consists of a thin plate of cemented-carbide with a hard coating, which is affixed to the basis-tool. The measurement is carried out at the rear of the plate, where the infrared conductive diamond window is fixed. The thermal black body radiation passes the window and is guided to a thermographic camera's lens by a deflecting mirror of polished aluminium. However, when tools are equipped with different coatings, the respective temperature coefficients have to be determined separately, irrespective of the investigated machining process.

The system was evoluted in a way, that the diamond window and the cemented carbide plate could be omitted in the set-up (Fig. 1). The eroded hole was designed in a way, that there was a rest—thickness of approximately 100 μm to the tools surface. Tests with uncoated cutting tool inserts showed that the measurements are valid up to the former system [3]. The greatest advantage of the evolution is the possibility of increasing the process parameters up to series parameters. The older system was limited according to the machining parameters, because with increasing process forces caused by risen cutting depth, the cemented carbide plate broke very fast.

Parallel to the modification of the system there were made several applications regarding to other tool machining operations (drilling, thread forming, milling) which were part of the project.

3. 'In-situ' temperature measurement at dry drilling operation

When dispensing with the use of coolants in metal removal operations, the increased friction involved and the simultaneous lack of heat dissipation will result in an increased temperature load on the tool. Specifically in drilling, as a process with concealed cutting edge, friction between the land and the borehole wall also become effective apart from chip surface friction. In addition to this, the tool heats up during disposal of the hot chips from the bottom of the borehole.

For determining the maximum temperatures occurring on the drill and the workpiece, a measuring arrangement has been developed by the DaimlerChrysler Research Centre, Ulm and the Institute of Production Engineering and Machine Tools (PTW), University Darmstadt. The maximum tool temperature occurs at the maximum borehole depth and is, therefore, measured at that point. If the thickness of the test workpiece is adapted to the desired borehole depth, measurement will have to be made at the time when the bit of the drill passes through the workpiece bottom. Prior to this also, the progressive heat-up of the workpiece can be recorded. For recording the temperature of the tool and the workpiece, the heat radiation emitted is determined by contact-free means via the thermographic camera system. Beneath the workpiece, the 45° deviation mirror is arranged in a guide system permitting height adjustment. On the exit side of the mirror, the camera is fixed (Fig. 2a). Prior to

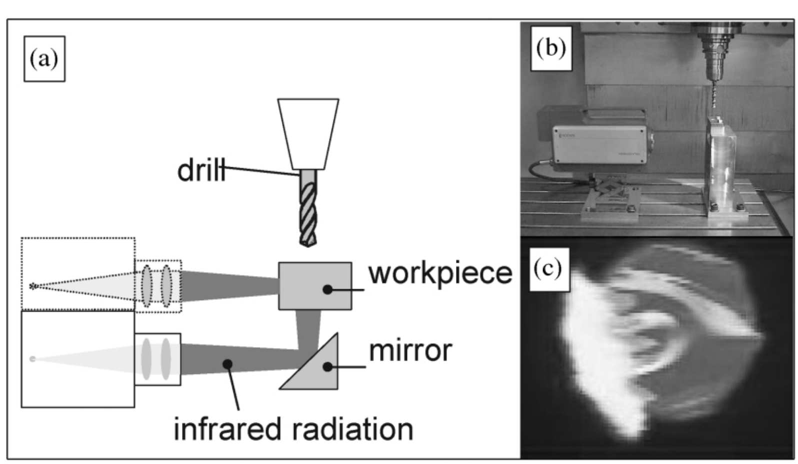

Fig. 2. Scheme of the set-up (a), the test installation (b) and the temperature distribution on the tool (c) [5].

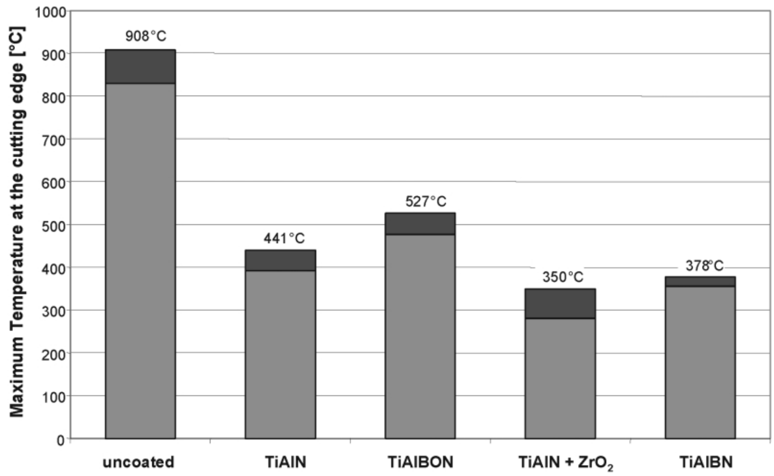

Fig. 3. Maximum temperatures at the cutting edge in drilling steel.

measurement, the camera on its elevator table is adjusted to the workpiece tower, so as to be focused on the bottom of the workpiece (Fig. 2b). Measurement during the drilling process is divided into two phases. As the tool cuts through the material, the heat-up occurring ahead of it can be recorded at the bottom of the workpiece. During the second phase when the tool passes through the workpiece bottom, the temperature in the area of the cutting edge and specifically at the cutting edge corners, which are subject to high thermal stresses is determined.

Fig. 2c shows an example of the temperature distribution on the top of a drill directly after the end of the drilling process (the feed had already stopped). The cap of the drilling hole is still sticking on the work material. It is possible to determine the temperature of single spots by the thermographic systems analysing software, which allows one to derive reliable knowledge about high temperature strained regions on the tool. When machining steel Ck45 with a TiAlN coated carbide tool (diameter 6 mm, cutting speed 85 m/min, feed 0.2 mm, depth 18 mm) a maximum cutting edge temperature of 441 °C could be detected.

4. Measurement results—drilling

Fig. 3 shows the measured maximum cutting edge temperature for different coating systems. For statistic reasons every drilling tool was tested four times.

The dark top areas in the diagram represent the range of the different maximum temperatures measured. The absolute maximum value is shown at the top.

With the uncoated tool, extremely high maximum temperatures up to 908 °C were detected at the cutting edge. All coating systems, the standard TiAlN, the boron containing and the oxide coatings could significantly reduce the appearing temperature in comparison with the uncoated tool. Of all coated tools the TiAlBON coating reached the highest maximum temperature of 527 °C. That indicates that the friction behaviour of TiAlBON is not as good as of the other coated test drills. The lowest temperatures of 378 and 350 °C, which indicates adequate friction behaviour, were reached with the TiAlBN and TiAlN–ZrO_2 coated tools.

5. Summary

The investigations of dry machining processes have shown that the developed test set-ups make it possible, to analyse and to attain deeper knowledge about the cutting processes. The use of a high resolution thermographic systems in combination with the measurement of the tools wear marks is a system to classify for example, different dry lubricant coatings and make them comparable. It has been shown that a reduction of the thermal stresses using special coatings is possible. The result can be a reduction of the wear and an increase in the tool life.

This scheme aids the researcher in founding a database of precise results about the temperature influence when using different coatings in the cutting process. This device could furthermore be utilised in the examination of various tool-geometries and substrate materials.

In summary there is a high potential for using this measurement system in various machining applications and also a high potential for optimising and further developing suitable self-lubricant coated tools for dry machining processes.

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