Comparison contact and thermal imaging methods measure the temperatures of the turning blades during cutting

Porównanie stykowych i termowizyjnych metod pomiaru temperatury ostrza tokarskiego podczas skrawania

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The paper presents a method of measuring the temperature during cutting and its impact on the machining process. The influence of temperature on the intensity of the cutting tool wear cutting and durability. Shows the measuring position, the materials used and the cutting tool. We present the results of the processing parameters, during which the measurements are made. This paper presents methods for measuring the temperature of the blade using a thermocouple and methods of radiation. It lists the advantages and disadvantages of each method.

KEYWORDS: tool wear, boron nitride, temperature measurements, cutting temperature, thermocouple, thermography, emissivity

Due to the phenomena accompanying material separation in the cutting process, heat is generated which results in a temperature increase in both the workpiece and the chip as well as the cutting tool. It is most undesirable to increase blade temperature [1, 2]. For tool materials such as high-speed steels, cemented carbides, ceramics or super-hard materials (polycrystalline diamond, boron nitride), increasing the working temperature in certain ranges can adversely affect the tool life. This is often related to the deterioration of the mechanical properties of the tool material (hardness decrease) and to the intensification of some wear phenomena, such as adhesion and chemical wear [3, 4]. In general, use of tools with very high hardness and abrasion resistance (such as superabsorbent materials: boron nitride BN and polycrystalline diamond PCD, adhesion and chemical processes are often important, intensification which can significantly reduce the blade life [4]. The relationship between the wear intensity of the blade and the cutting temperature is very complex and not always monotonic.

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Due to the economics of machining and environmental protection, machining without the use of a lubricating oil is increasingly used. Consequently, the research upon tools and tooling materials (and coatings) is being conducted to reduce tool wear associated with increased operating temperatures [5].

Authors are focused on the choice of the cutting temperature measurement method for transverse turning using a cutting tool made of modern cubic boron nitride and tungsten carbide in cobalt matrix (WCCo/cBN).

Purpose of research

The aim of the study was to develop the most advantageous method for measuring the cutting temperature during transverse turning using a WCCo/cBN composite cutting insert tool. Plate geometry was standard (marking according to ISO 243 or NNPa-c according to PN/M-58352). The machining was carried out without the use of a cooling lubricant on the numeric lathe DMG CTX 210. The workpiece was GJL-250 spheroidal cast iron. The input material was a cast iron shaft with an initial diameter of 130 mm, mounted in a hydraulic triple handle. Additional support was applied in turning laths. The tests were performed at various cutting speeds ranging from 125 to 250 m/min and depth feedrate of 0.06 and 0.1 mm/rev.

Measuring the cutting temperature

The need arose to develop a method for measuring the tool temperature during machining. The method should minimize interference in the cutting process, be fast, and offer the ability to measure and acquire results online without interruption. Due to the operator's safety, it was possible to place the measuring system inside the lathe work area and close the work area shield.

Two methods of temperature measurement were proposed. The first one was the thermal method using the FLIR T620 and FLIR ReseachIR MAX software [5]. The camera was placed in the working area of the machine tool and directed towards the blade at an angle allowing continuous observation of the auxiliary relief surface and part of the rake surface [6]. The view of the thermal imaging camera is shown in fig. 1.

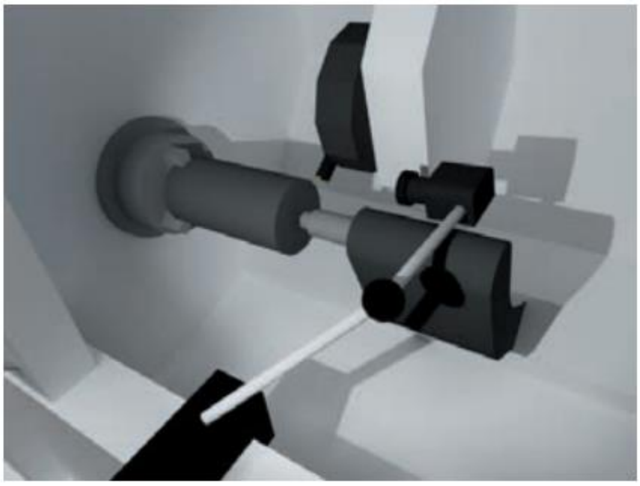

Fig. 1. The positioning of the thermal imager in the working space of the machine

The second method proposed - contact method - uses a calibrated thermocouple type K. It has a reference role to the method of using a thermal imager. The problem with contact measurement was the placement of the touch probe near the cutting zone. In the lateral surface of the blade an opening is made in which a measuring joint is inserted. The hole was made with a dip electrode and a copper electrode. To ensure a good thermal conductivity between the tool material and the thermocouple, the hole space was filled with a heat-conducting paste. The hole and its location are shown in fig. 2. Due to the reduction of the active cross section of the blade at the critical point, where the hole was made, the depth and dimensions of the hollow hole had to be reduced, increasing the risk of tool damage due to cutting forces.

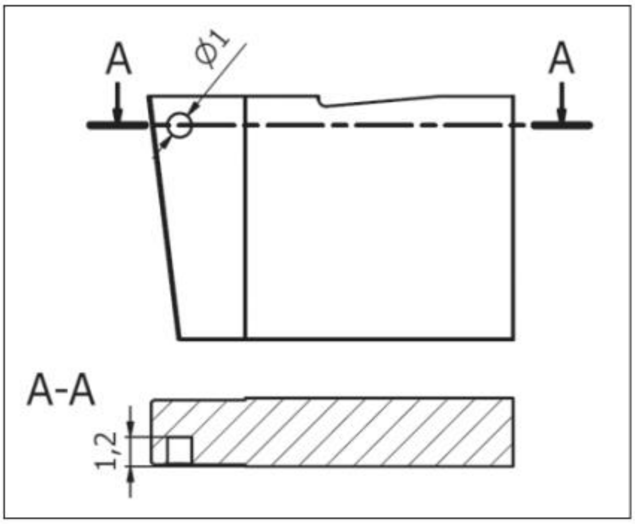

Fig. 2. Dimensions and location of the measuring hole in the blade

Contact cutting temperature measurement

The contact temperature measurement was performed using a K-type (NiCr-NiAl) bead thermocouple, measuring instrument by National Instruments and LabVIEW software. The measuring probe was placed in the hole made in the cutting edge and remained in contact with the test material via a heat-conducting paste (fig. 3). The results are shown in graphs of temperature in time (fig. 4 and fig. 5). Temperature measurement by contact method was a reference for thermal imaging measurement.

Fig. 3. Thermocouple placed in tool - need to attach additional probe cover

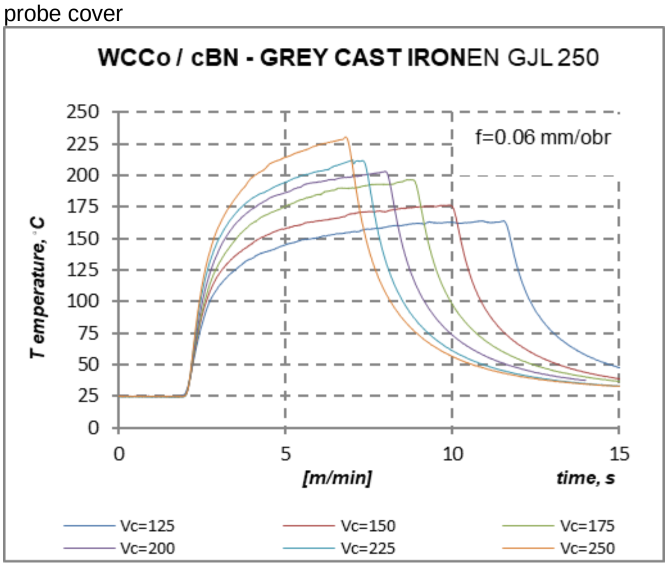

Fig. 4. Temperature vs. time in the cutting process with feedrate f = 0.06 mm/rev

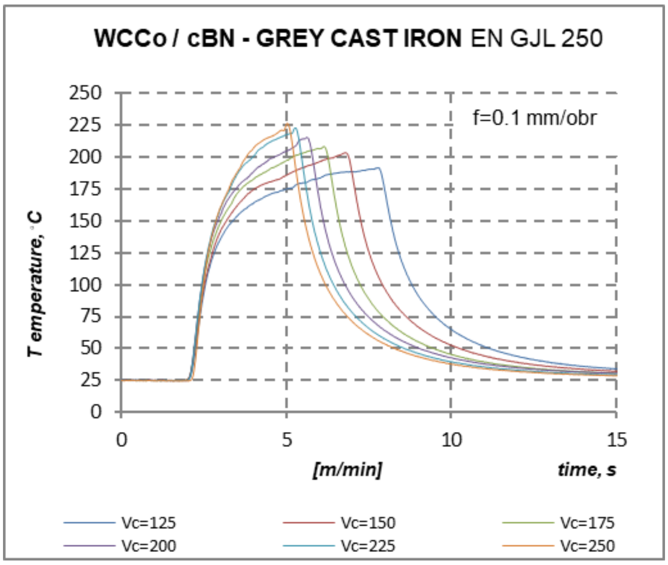

Fig. 5. Temperature vs. time in the cutting process with feedrate f = 0.1 mm/rev

In the graphs (fig. 4 and fig. 5), it can be seen that the cutting temperature increases with the cutting speed v_c and the feedrate *f*. The feedrate *f* has a greater influence on the temperature than the cutting speed v_c. This guarantees the shorter time to reach the set temperature on the surface being measured.

Thermographic cutting temperature measurement

The characteristic feature of thermal imaging cameras is the indirect measurement of the temperature based on the power of infrared rays falling on the detector and the conversion of this signal into the measurement path of the camera on the carrier of the temperature information of the electrical signal. To measure with the use of a thermal imager, it is necessary to know the parameter describing the thermal properties of the object - the effective emissivity ε. The emissivity parameter depends on many factors such as the state of the surface layer, reflective properties, and temperature. It was necessary to know the coefficient of emissivity of the cutting blade used to measure the blade temperature during cutting using a thermal imager. This emissivity was determined as a function of temperature by means of a laboratory heater [7, 8] to warm up the sample and to maintain a steady temperature on the surface (fig. 6). The cutting edge temperature was measured at the same tool point (at the same distance from the corner of the blade) as in the contact method.

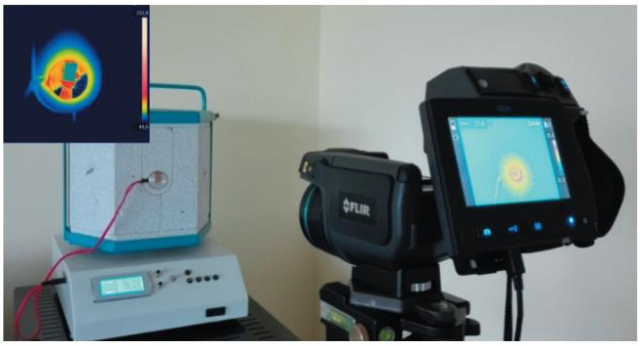

Fig. 6. Position for determining the coefficient of emissivity

The emissivity coefficient ε introduced into the camera system for the examined blade was read and taken from the obtained characteristic (fig. 7) in the interval corresponding to the thermocouple contact temperature measurement.

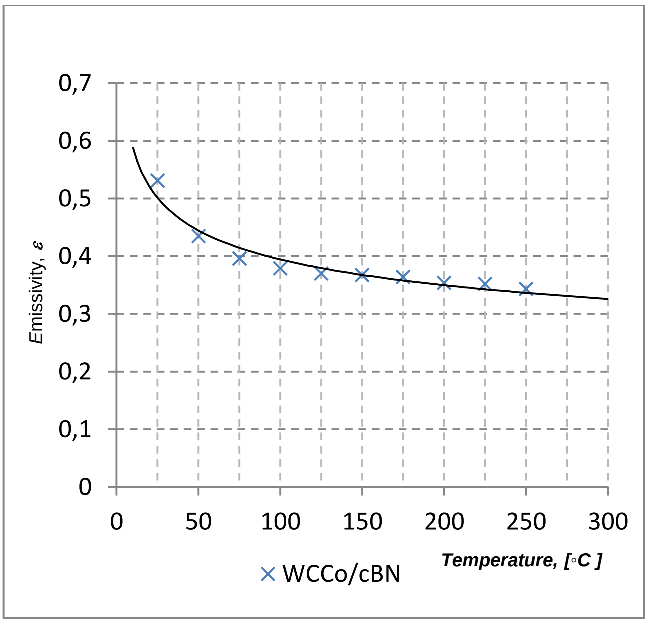

Fig. 7. Curve of emissivity coefficient vs. temperature for blade surface made of WCCo/cBN

Analysis of results - comparison of methods

The results obtained by contact (reference) method were compared with radiation measurements. This is presented in the form of graphs (fig. 8 and fig. 9).

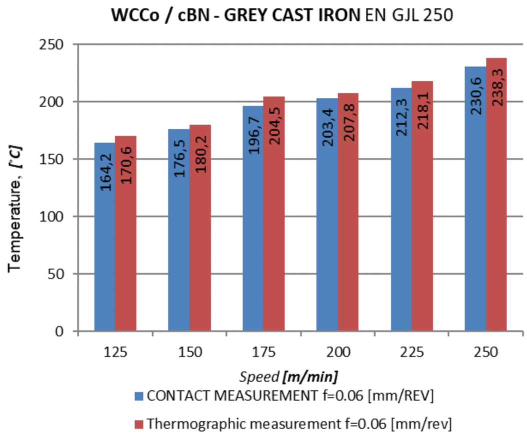

Fig. 8. Comparison of maximum temperature in time during the cutting process for different cutting speed parameters vc at feedrate f = 0.06 mm/rev.

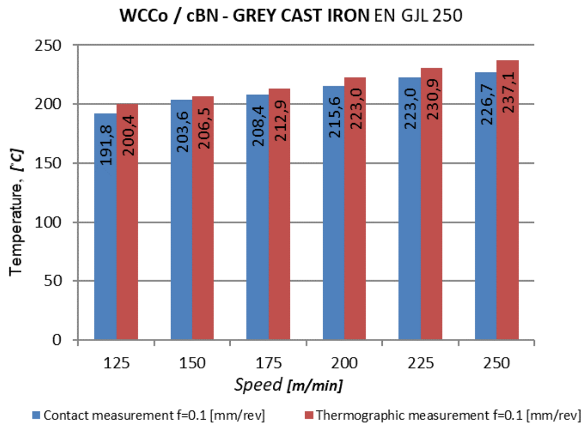

Fig. 9. Comparison of maximum temperature in time during the cutting process for different cutting speed parameters vc at feedrate f = 0.1 mm/rev.

The temperature values measured by the thermal imaging method, similarly to the contact method, are coherent and grow with the increase of the cutting speed v_c and the feedrate *f*. The advantage of using a thermal imaging camera is the ability to observe the heat distribution across the entire surface of the element being measured, which is impossible at contact measuring. Thermographic measurement also eliminates convection and heat capacity as well as inertia of sensors. The disadvantage of the thermal imaging imethod is the need to know the coefficient of emissivity of the material under test in terms of the temperature, at which the basic measurement will be performed.

Accurate temperature measurement using a thermal imaging camera is not possible with reflective materials. This method is sensitive to interference, among others, through shavings entering the field of view of the camera. Thermocouple measurement is characterized by less distortion. The measuring probe is located inside the object under test and is isolated from interfering external factors. The disadvantage of this method is the ability to measure only one point and the need to ensure contact with the examined element [9].

Conclusions

The studies allowed to determine the blade temperature at the measuring point during cutting using two independent methods. Both methods yielded convergent temperature values, and the largest difference between the specified processing parameters did not exceed 11 °C. It is noteworthy that the thermo imaging method can yield more measurement data, but more than the contact method, it is sensitive to interference, so its use is significantly limited.

Achieved results can be used to evaluate the temperature, at which the tool runs during the cutting process at various machining parameters, and to help optimize the cutting process while maintaining the tool life. The cutting temperature during insertion of the blade into the material gives important information regarding the tool heating and cooling rates and the maximum cutting edge temperature at the measuring point during the machining process. Correlation of temperature with cutting parameters, combined with comprehensive blades wear analysis, may allow to conclude about the wear processes occurring during operation and to select optimal cutting parameters to increase the tool life of composite materials.

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