Temperature measurement using natural thermocouple during grinding with monolayer grinding wheel

Pomiar temperatury za pomocą termopary naturalnej podczas szlifowania ściernicą jednowarstwową

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Presented is an example of temperature measurement during grinding of high-alloy steels with electroplated cBN grinding wheel. The grinding material and the nickel tape formed a natural thermocouple used for the measurements. A method for gaining the thermal characteristic of natural thermocouple was proposed.
KEYWORDS: grinding temperature, temperature measurement, natural thermocouple, monolayer cBN grinding wheels

High temperatures in the grinding process can lead to damage of the work surface such as, for example, cracks, phase changes in the surface layer, hardening and fatigue strength. In addition, due to the thermal expansion, the dimensions of the workpiece (WP) can change during grinding, which results in the formation of dimensional errors [1]. It is therefore important research aspects of thermal process grinding.

Temperature measurement in the grinding process, and above all the interpretation of its results are not easy issues. Difficulties in the registration signal may be due, among others, kinematics of the process and limited access to the research area [2]. Problems with the analysis of measurement data are caused by:

- the occurrence of very large temperature gradients in time and space in the vicinity of the contact surface and the wheel WP,
- a measurement area much larger than a single heat source around cutting edges,
- difficult to determine the effect of coolant on the result of a single measurement (per one pass of the wheel) and its change over time [1, 2].

For this reason, relatively little work is done on the subject in the context of single-layer grinding [3-6]. Much more attention is paid only to the effects of too high temperature in the grinding zone in the form of grinding burns which may be a symptom of wheel wear [7, 8].

The paper attempts to use a natural thermocouple to determine the temperature when grinding high alloy steels with a cBN grinding wheel with a galvanized binder.

Calibration of the natural thermocouple

One of the thermocouple thermoelements is the ground material. The ground material is very rarely used for the structure of industrial thermocouples, and therefore there is a need to determine the characteristics of the natural thermocouple used.

In the case of the thermocouple used on the test bench, the nickel tape and ground material, i.e. Pyrowear 53 after thermal-chemical treatment (TCT), were used.

The first calibration tests were carried out using a Fluke 9150 thermocouple calibrator. Apart from the furnace display reference, reference temperature information was provided by the J-type thermocouple (fig. 1).

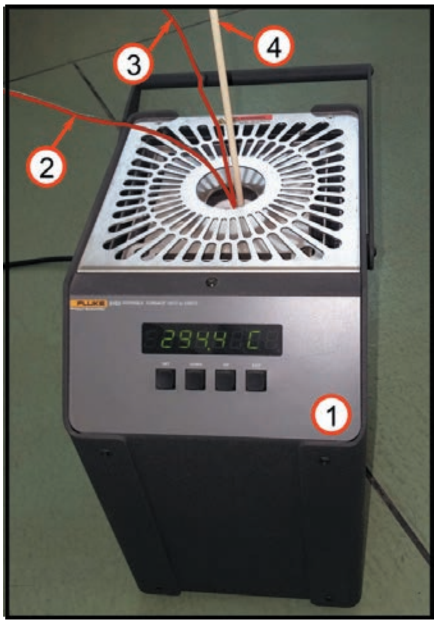

Fig. 1. The thermocouple calibration furnace (1) with the calibrated thermocouple (lines 2 and 3) and the reference thermocouple (4)

Because of the small furnace space, Pyrowear 53 thermocouple components were prepared in the form of wire with a square cross section and a side about 1 mm, while the nickel was round wire with a diameter of 1 mm. The steel wires after the carburization became very fragile and often broke during further heat treatment, transport and connection to the second thermocouple element. Ultimately, the Pyrowear 53 components were about 10 cm long, so they were extended with a compensation wire that led to the card. The nickel was long enough that its free end could be directly connected to the card. The small dimensions of the steel components caused them to heat up quickly over the entire length, and thus the need to change the configuration of the calibration station so that an approximately constant temperature of the cold end of the thermocouple could be maintained.

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The second, final concept of the thermocouple calibration bench is shown in fig. 2.

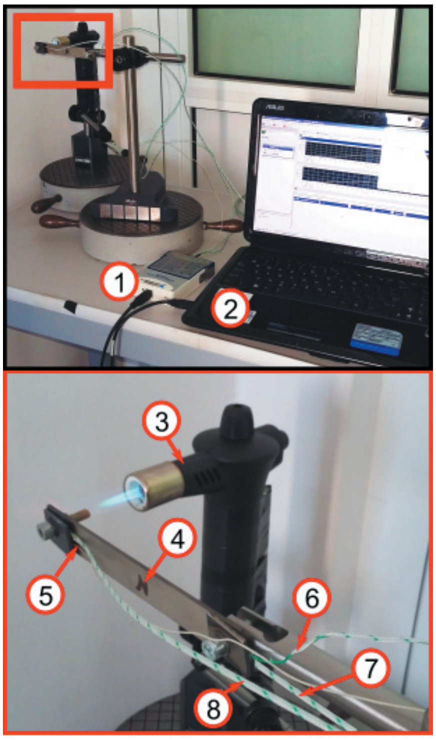

Fig. 2. Stand for calibrating the thermocouple (1), PC (2), gas burner (3), steel thermocouple element (4), nickel thermocouple element (5) (6), thermocouple measuring the temperature of the cold end of the steel element (7), reference thermocouple relative to the calibrated one (8)

Pyrowear 53 thermocouple was prepared in the form of a 150×18×3 mm plate (4). Smaller pieces of the same material were tightened to the ends of the plate. At the hot end of the Pyrowear 53 plate, which was heated by a gas burner (3), the nickel wire (5) (thermocouple calibrated thermocouple) and the K type reference thermocouple (8) were clamped between the steel elements. At the cold end of the steel plate, the compensation wire is disconnected from the steel plate (6) and the K type thermocouple, which measures the temperature of the cold end of the steel plate (7). Signals from all thermocouples were added to the NI-9211 measurement card and recorded using LabVIEW SignalEkspress.

To ensure more credibility, the experiment was repeated twice. The heating process was done as soon as possible to minimize the cold end temperature change. During the calibration of the thermocouple as a result of heating the steel plate, the cold end temperature changed by a maximum of 32 °C, which constituted 5.5% of the maximum recorded temperature.

The calibration results were carried out for the cooling phase, which consisted in leaving the samples in calm air. The results of both repetitions are shown in fig. 3.

In order to determine the characteristics of the thermocouple after averaging the values from the two trials, regression analysis was performed.

In fig. 3, it is clear that above the temperature of about 100 °C, the relationship between the electromotive force (SEM) and the temperature is linear. Then the characteristics of the thermocouple can be approximated by:

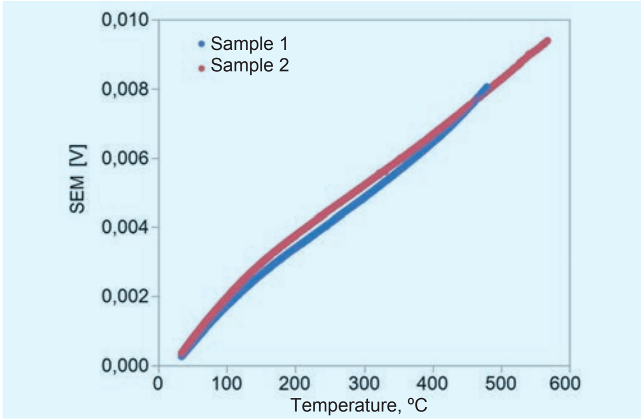

Fig. 3. SEM electromotive force values according to temperature in two samples representing natural thermocouple

$$T\ [^{o}C] = 0{,}000405 + 1{,}55e\text{-}5 \cdot SEM\ [V]$$

The results of the regression analysis are shown in the diagram (fig. 4).

Linear regression equations can be considered as significant for the significance level $\alpha < 0.0001$. The correlation coefficient r between data representing the dependent variable and the independent variable was equal to the condition $r \geq 0.99$ for both samples.

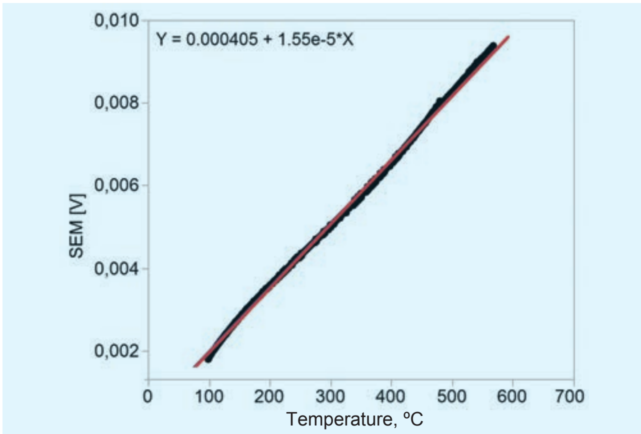

Fig. 4. Regression line describing the characteristics of the thermocouple

Temperature measurement on the test bench

The grinding process of the high alloy steels of Pyrowear 53 was carried out on a Fortis sandblast by Michael Deckel using a single-layer grinding wheel with a brazing platen with a cBN abrasive with B35 grain size number. The wheel had a conical shape with a maximum diameter of d_s = 100 mm and a cone angle of 140°.

The wheel speed was n = 6000 rpm, feedrate v_w = 1400 mm/min, grinding depth a_e = 30 μm. The grinding time in one pass of the grinding wheel was about 1.74 seconds.

For the temperature measurement, a natural thermocouple was used, which is shown in fig. 5. The thermocouple components were the ground material and nickel band. To isolate them from each other, the sides of the sanded samples that adhere to the Ni tape were covered with an insulating paint. As the temperature signal turned out to be too weak, a signal amplifier ×100 was set up to distinguish it from the measurement noise. The amplification signal was transferred to the NI USB-6215. Data acquisition in the form of TDMS files was performed in LabVIEW Signal Express. For the TDMS file processing, the Python development environment was used.

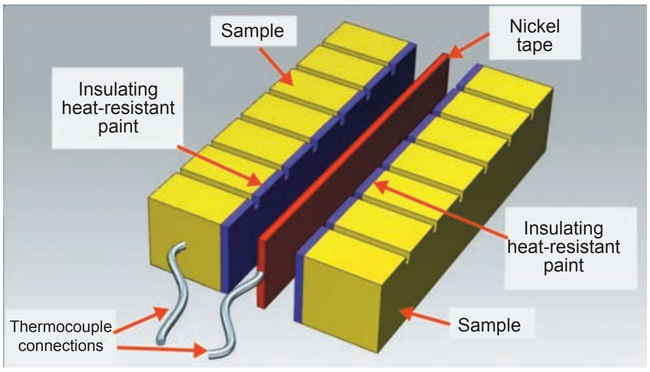

Fig. 5. Diagram of the construction of the natural thermocouple used in the tests

An example of the signal recorded for the next three grinding wheels is shown in fig. 6. An increase in the value of the temperature signal is observed when the thermocouple components are connected and drop is seen after their disconnection.

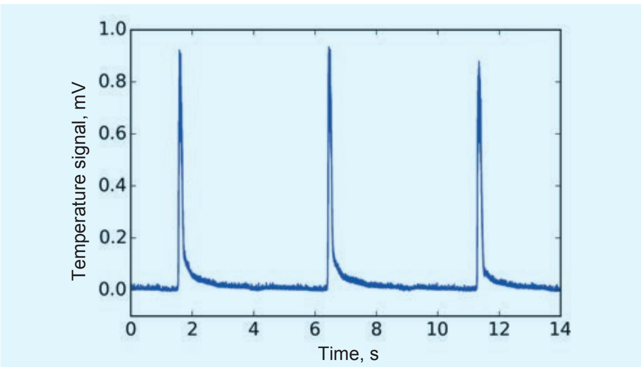

Fig. 6. Example of a recorded natural thermocouple signal for the subsequent three grinding wheels

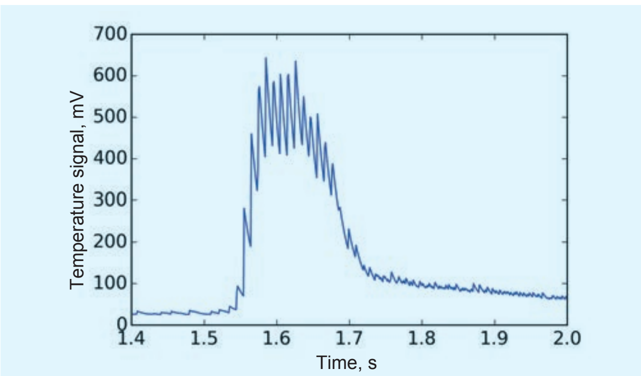

Fig. 7. Temperature values during a single grinding wheel passage

Fig. 7 shows a portion of the recorded signal after unit conversion to a temperature in degrees Celsius, using a pattern determined during the calibration of the thermocouple. It can be seen that the peaks of about 600 °C have the same frequency as the rotating grinding wheel.

Similar observations were made by the author [3, 4] (fig. 8), who interpreted the maximum value of peaks as a single grain grinding temperature, which in the cited studies was 500÷600 °C.

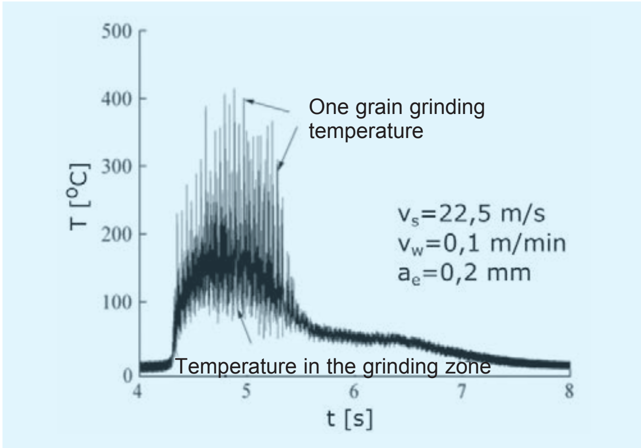

Fig. 8. Example of recorded temperature signal during grinding with discrete grinding feed with cBN abrasive [4]

Conclusions

The proposed method of determining the characteristics of the thermocouple is burdened with an error resulting from the failure of the constant temperature of the cold end of the thermocouple. It can be eliminated if the cold ends of the thermocouples are placed in water and ice tanks, but this complicates the construction of the station. Due to the relatively small change in temperature of the cold end of the steel plate during the thermocouple calibration test (approx. 5.5%), the authors of the article considered the methodology used for the research acceptable enough to determine the approximate temperature during grinding.

Both the nature of the recorded temperature signal and its values agree with the data obtained in other studies [3, 4, 6], suggesting the correctness of the test results.

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