Some Features of Measuring Grinding Temperatures

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Abstract Under the influence of the grinding temperature, phase and structural transformations occur in the surface layer of the latter, which reduce the reliability and durability of operation by 2–3 times. It should be noted that any temperature value causes the appearance of some residual stresses. then phase and structural transformations occur. Since the temperature values of points Ac1and Ac3 can vary depending on the chemical composition of the steel being grinded and on the processing conditions, it is fundamentally important to establish the laws of these changes. This paper describes methods for measuring temperature on samples with microthermocouples in the form of wires, the diameter of which is 20 -100 μm, i.e. there is less then distance between the grains of the grinding wheel, which eliminates cutting by microthermocouples with several grains at once, which greatly improves the reliability of the results. The method of measuring temperatures when grinding non-electrowire materials is described. The article describes a temperature sensor built into the circle, which allows measuring the grinding temperature directly at the workplace .In the article, mathematical calculations are given that allow you to get the true values of grinding temperatures depending on thermocouple materials and parts materials.

Keywords: Contact temperature, instantaneous temperature, pulse temperature, microthermocouple, thermal sensor.

1 Introduction

The temperature in the contact zone of the wheel with the part is the most important characteristic of the grinding process. Under the influence of the grinding temperature, which can reach the melting temperature of the material of the part in the surface layer of the latter, phase and structural transformations occur, which reduce the reliability and durability of operation by 2 to 3 times .

Essentially, the grinding temperature produces additional heat treatment of the surface layer of the part, which is not provided for by the technology of its manufacture. It should be noted that any temperature value causes the appearance of some residual stresses, then phase and structural transformations occur when the temperature reaches the points Ac1 and Ac3. (1.2. Since the temperature values of these points can vary depending on the chemical composition of the steel being grinded and on the processing conditions [1,2], it is of fundamental importance to establish the laws of temperature change as a function of the processing conditions and the characteristics of the circle. Analytical analysis [1, 2,] makes it possible to establish general patterns that need experimental verification, which can be done by direct measurements of the grinding temperature. First you need to determine what we will measure, since the concepts of “temperature grinding method ”includes the following components — contact temperature or temperature averaged over the contact spot of a circle with a part, instantaneous temperature or temperature from a single grain and pulse temperature, which is equal to the sum of the two mentioned. [3]. It should be noted that measurements can be carried out on samples and on specific details during their processing on the machine.

At present, the method of measuring the temperature of sintering on samples with foil embedded microthermocouples is widely used. The thickness of the foil is 20 - 30 microns, when grinding when cutting the foil, a microspai is formed. Such a microthermocouple has low inertia and confidently registers not only the contact temperature, but also the instantaneous temperature from the grains. However, due to the fact that the width of the foil microthermocouple is several millimeters, it can be simultaneously cut by several grains, as a result of which an incorrect result will be obtained when measuring instantaneous temperature. To avoid this, the width of the thermoelectrode or its diameter, if a wire is used, should be less than the distance between the cutting grains. In this case, impulses from grains following strictly one after another will be obtained. This will allow not only to correctly determine the instantaneous temperature, but also to determine the number of really cutting grains, the average thickness of the chips removed by the grain, and also, by some calculations, the conditional radius of curvature of the cutting tip of the grain. In addition, the heat flux of the grinding temperature can cause different heating temperatures of the thermal junction and the surface to be grinded. An electrical signal from a thermocouple characterizes the temperature of the thermal junctionwhich must be brought to surface temperature. There are no such calculations in works devoted to measuring grinding temperatures.

Measuring the grinding temperature of actually machined parts is carried out by various temperature sensors and infrared radiation detectors, which are built into the circle or trap infrared radiation through the hole in the circle. This work is devoted to some features of temperature measurement both on samples and on real details .

2. Literature Review

At present, there is an extensive literature on measuring the grinding temperature, however, the relationship between the signal and the surface temperature, rather than thermal junction, has not yet been sufficiently considered. In addition, the issues of measuring the grinding temperature directly during grinding of a particular part are not described fully enough and rely mainly on rather complicated and expensive equipment.

So in [4], temperature measurement was described using foil thermocouples to consider the energy distribution in the workpiece. The work was performed at a high level, however, the use of foil thermocouples, due to the fact that the thermocouple can be cut by several grains at once, which can introduce an error into the measurements.

The question of the ratio of the temperature of the thermal junction to the surface temperature has not been considered.

In [5], a technique is described for measuring the grinding temperature with thermocouples. Descriptions of the temperature distribution in the grinding part are presented. The question of possible measurement errors when cutting a foil thermocouple with several grains at the same time was not considered. The relationships between the temperature of the thermal junction and the surface temperature are not considered.

In [6], issues of monitoring the grinding temperature during processing were considered. The dependences of the grinding temperature on the processing parameters are considered. The temperature ratios of the thermal junction and the surface of the part are not considered.

In [7], using foil thermocouples, the distribution of thermal energy between a circle and a part is studied. It is concluded that the most reliable results were obtained only in the cooling phase. Foil thermocouples were used with the inherent disadvantages indicated above.

In [8], the temperature field was studied during grinding with a small “creeping” feed of the root of a turbine blade. Used digital modeling and experiment. Good convergence of the results was noted. The method is not specified how the power of a heat source is theoretically determined during modeling. There are no correlations between the temperatures of the thermal junction and the measurement surface.

The work [9] describes the operation of an integrated platform for measuring the grinding temperature. Good agreement between the results of theoretical calculations and experimental measurements is shown. The issue of measurement errors is not adequately covered.

In [10], the measurement of the surface grinding temperature by an infrared sensor is described. The method involves measuring only the contact surface temperature, and in the phase of the onset of cooling. The measurement scheme is quite complex, but can be used when grinding a specific part.

In [11], the process of controlling the grinding temperature by a high-speed air flow, which is fed into the contact zone, is considered. There is a decrease in temperature measured by foil thermocouples, which are characterized by the above disadvantages. As can be seen in all cases, it is not determined by the ratio between the received signal from the thermocouple and the real surface temperature.

3 Research Methodology

The purpose of this work is:

- a statement of the method for measuring grinding temperatures by microthermocouples, which, thus excluding, excludes the cutting of the thermoelectrode by several grains at the same time, which eliminates the error in measuring the instantaneous temperature and which contains a method for linking the temperature of the thermal junction to the surface temperature;
- a description of the method for measuring temperature by microthermocouples when grinding samples from non-conductive materials;

- a statement of the method of measuring surface temperature when grinding a real part using a temperature sensor built into the circle.

Of the currently developed methods for measuring grinding temperatures, the method of sheared semi-artificial microthermocouple, consisting of the metal being processed and the thermoelectrode placed in the grinded part, is the most affordable and convenient, giving a visual distribution of the temperature in the cutting zone and allows recording and measuring the cutting temperatures of individual abrasive grains directly in the grinding zone. One of the electrodes of such a microthermocouple is the workpiece, and the second thermoelectrode is a constantan wire with a diameter of 20 μm. The diameter of the wire is much smaller than the distance between the cutting grains of almost any grain size, which excludes cutting it with several grains at once.

After installing the thermoelectrode in the sample (Fig. 1), the end of the latter is displayed on the surface of the sample and polished. During the experiment, contact, instantaneous, and pulsed temperatures are measured simultaneously; therefore, it is necessary to calculate the time and frequency characteristics of the measuring paths.

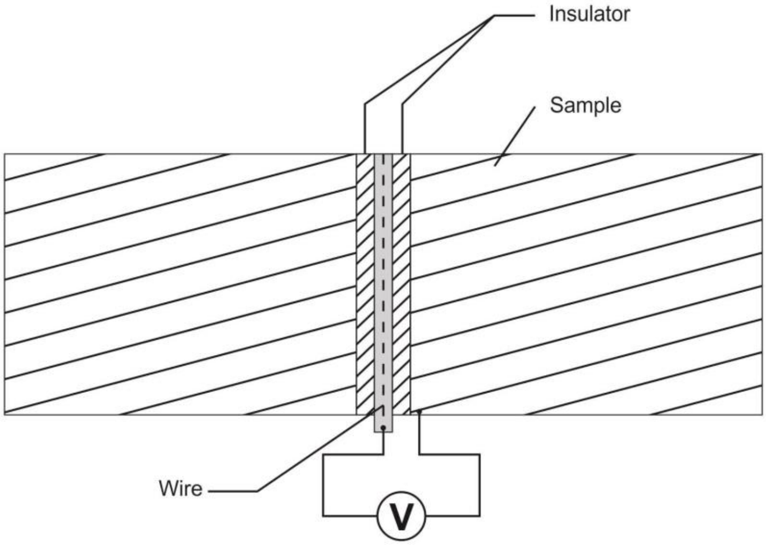

Fig. 1. Sample with thermocouple "thermoelectrode - part"

The characteristic pulse recorded by the storage oscilloscope has the form Fig. 2

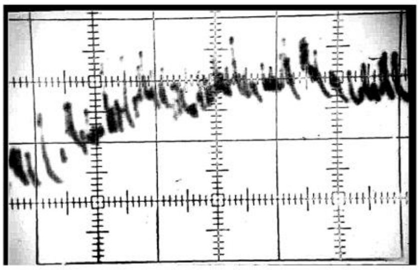

Fig. 2. A typical thermal impulse. Sweep speed 3 ms per 1 cm

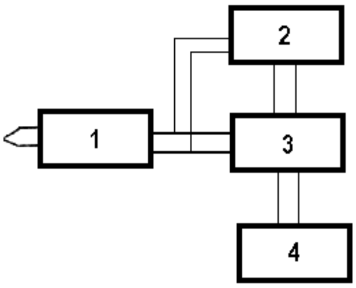

Fig. 3. Block diagram for measuring grinding temperature. I - signal amplifier, 2 - sweep trigger amplifier, 3 - amplitude recording oscilloscope, 4 - pulse duration recording oscilloscope. 10 MHz measuring pat

Since during the formation of a thermocouple “thermoelectrode-part” occurs, the signal of such a thermocouple will correspond to the temperature of the thermocouple, while it is necessary to determine the surface temperature of the part. Both the surface temperature and the temperature of the end face of the thermoelectrode can be described by the expression (3):

$$T_{surf} = \frac{1{,}12Q\sqrt{\tau}}{F \times \varepsilon} \tag{1}$$

where: Q – power of a heat source, W

F – is the area of the contact spot of the circle with the part, m^2

T_{surf} – determined temperature, °C

ε – is the coefficient of thermal activity J/m^2 °C sec$^{0.5}$, moreover;

where: λ – is the thermal conductivity coefficient J/m sec deg,

C – is the specific heat J/kg deg, ρ is the density kg/m^3.

Using the dependences of contact heat transfer [12] we obtain the expression for the surface temperature:

$$T_{surf} = T_{cont}\frac{\varepsilon_{surf} + \varepsilon_{thc}}{2\varepsilon_{surf}} \tag{2}$$

or

$$T_{surf} = T_{cont}\frac{\varepsilon_{surf} + \varepsilon_{thc}}{2\varepsilon_{surf}} E \cdot j = \kappa_1 \cdot \kappa_2 \cdot E \tag{3}$$

where

$$\kappa_1 = \frac{\varepsilon_{surf} + \varepsilon_{thc}}{2\varepsilon_{surf}} \cdot j \tag{4}$$

and E – is the value of thermoelectric power,

j – is the coupling coefficient between the temperature of the thermal junction and thermo-electromotive force current (thermos-e.f.c)

k_2 is the gain of the circuit.

If it is necessary to measure the temperature during grinding of non-conductive materials, a sample of the following design is proposed for this (Fig. 4)

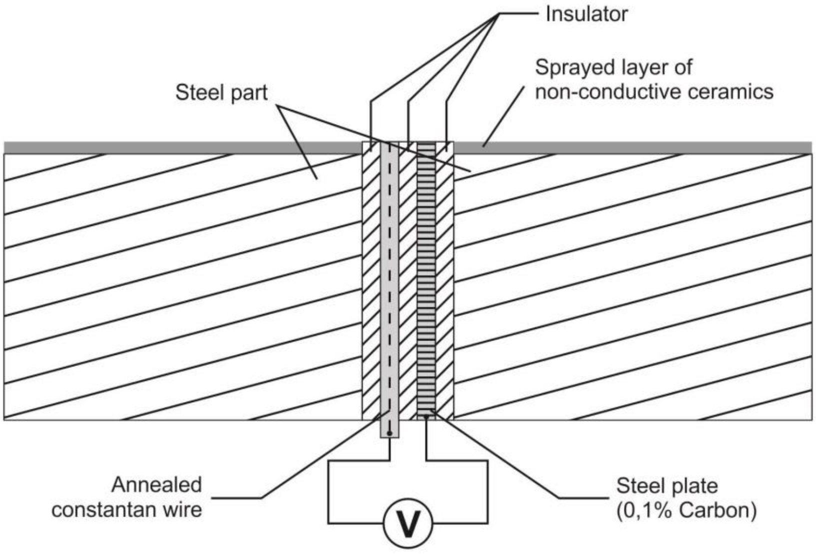

Fig. 4. Sample for measuring the grinding temperature of non-conductive materials

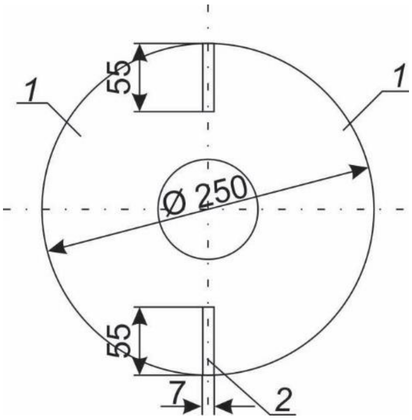

Fig. 5. Circle sensor.
1 – circle; 2 – sensor

The sample shown at Figure 4 is used to measure the grinding temperature of a non-conductive ceramic layer sprayed onto a steel base. During grinding, a constantan-steel thermocouple is created, the temperature of which is reduced to the temperature of the grinded ceramic according to formula (2).

To measure the temperature during grinding of a particular part, we used a temperature sensor built into the circle. The sensor meets the following requirements: – high measurement accuracy, low inertia, constancy of properties when editing a wheel the invariance of the roughness of the grinded surface, the ability to work with lubricating-cooling process media (LCPM), low cost.

The temperature sensor consists of two copper-constantan foil plates between which a gasket of non-conductive material is placed. Foil plates and gasket are glued together with epoxy adhesive under the press. The shape of the sensor corresponds to the shape of the cross section of the circle. The total thickness of the sensor is 1 – 1.5 mm. To install the sensor in an abrasive tool, a groove along the radius is cut in the last:

$$K = \frac{D_{\max} - D_{\min}}{2} \qquad (5)$$

where: K is the length of the groove, *mm*, D_{max} and D_{min} is the largest and smallest wheel diameter after editing. For ease of measurement, two sensors are installed in a wheel along the radius and are fixed with epoxy glue. Sensors are thus organic parts of the wheel. When editing, they are easily cut with ruling diamonds. The strength of the wheel after installing the sensors does not decrease, as the verification of the circle after installing the sensors shows at a speed of 1,5 of working. The drawing of a circle is shown at fig. 5. When grinding the wheel works as follows; The temperature sensors touch the surface to be treated, the foil petals are closed by this surface forming a copper-constantan thermocouple whose electrical signal is proportional to the surface temperature, the temperature of which is related to the sensor temperature by the ratio:

$$T_{surf} = T_{sen} \frac{\varepsilon_{surf} + \varepsilon_{sen}}{\varepsilon_{sen}}, \tag{6}$$

where: ε_{surf} and ε_{sen} coefficients of thermal activity of the surface and the sensor. If grinding is carried out using LCPM, the latter shunts the temperature sensor signal, introducing a certain error. To estimate this error, we consider the equivalent circuit of Fig. 6.

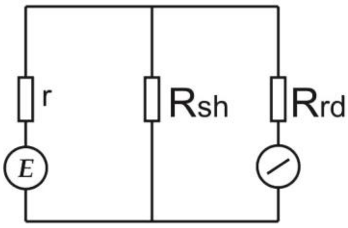

Fig. 6. The equivalent circuit of the electric circuit is a temperature sensor – collector device — LCPM. *r*- is the internal resistance of the temperature sensor, R_{sh} is the shunt resistance of the LCPM R_{rd} is the input resistance of the recording device.

The measurement error will be:

$$\delta = \frac{I \cdot r}{I\left(\dfrac{R_{rd} \cdot R_{sh}}{R_{rd} + R_{sh}} + r\right)} \tag{7}$$

Considering that the electrical resistance of almost all SOTS is greater than 1 kOhm, it can be argued that the measurement error is negligible. However, the measurement error is not limited to this.

The electrical signal of the sensor is proportional to a certain temperature, the value of which in general form can be expressed by the following relation:

$$U_{sen} = j\left\lfloor T_{surf} - \left(\Delta T_1 + \Delta T_2 + \Delta T_3 +\right) + \Delta T_{fr} \right\rfloor \tag{8}$$

U_{sen} – sensor voltage V,

T_{surf} – surface temperature of the grinded metal,

ΔT_1 – temperature drop due to the delay of the measurement moment,

ΔT_2 – temperature drop due to the short measurement period,

ΔT_3 – temperature drop due to thermal resistance,

ΔT_{fr} – the friction temperature of the sensor of metal.

Experiments show that the sum of the errors 1,2,3 is always negative, and the error of frictionis ΔTfr is always positive. These errors are about the same value and therefore cancel each other out. Therefore, the surface temperature through the temperature of the sensor is determined by the formula (6).

4 Results

Studies have shown that the use of wire thermoelectrodes with a diameter of 20 - 100 microns makes it possible to create "semi-artificial" thermoelectrode-part microthermocouples when grinding, which have very low inertia, which makes it possible to measure temperatures from a single grain during grinding. The use of these thermocouples makes it possible to obtain visual thermal pulses and to evaluate from them the relationships between contact temperature, instantaneous temperature and pulse grinding temperature. The latter is very important, since thermal defects of the polished surface can occur not only under the influence of contact temperatures, but also under the influence of pulsed temperatures, the duration of which is several microseconds.

The temperature sensor built into the circle makes it possible to measure the contact temperature of grinding directly when grinding a particular part, at a particular workplace. The electrical signal from the temperature sensor is a sequence of Π-shaped pulses that can be easily digitalized and can be used to measure the contact temperature of grinding, not only when grinding "dry", but also when grinding using any coolant. If necessary, the sensor signal can be used for controlling the grinding temperature process.

5 Conclusions

The proposed measurement procedure makes it possible to measure grinding temperatures on samples with high accuracy, eliminating errors in measuring instantaneous temperatures when the foil thermocouple is cut by several grains at once. The proposed methodology makes it possible to determine during grinding not only the temperature of the thermal junction, but also the temperatures of the surface being grinded, whose thermophysical characteristics may differ from the thermophysical characteristics of the thermo junction.

The proposed technique makes it possible to measure the grinding temperature of a particular part at the workplace and, if necessary, adaptive control of the grinding process can be based on it.

It is desirable to carry out the processing of measurement results in accordance with the methodology described in [13].

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