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In-situ measurement of the temperature inside the grinding wheel

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Abstract

During the grinding process, high temperatures are generated in the contact area through shearing and friction between the tool and the workpiece. These can damage the workpiece or alter its properties, e. g. introduce tensile residual stresses or change the microstructure through phase transformation. Therefore it is crucial to study the energy balance and especially the energy distribution between the grinding tool and the workpiece. Grinding wheels with high thermal conductivity have the potential to absorb more energy and shift the heat distribution away from the workpiece and towards the tool. In order to investigate the influence of the grinding wheel properties on the heat distribution, this study presents an approach to measure the temperature inside the grinding wheel. The measuring unit for the grinding wheel is clamped on the tool spindle in front of the grinding wheel and thermocouples are inserted into the bond of the grinding wheel. With this method, the energy balance of grinding wheels with sintered bronze bonding and different concentrations of CBN grains was investigated. It is shown, that the grinding wheel takes up more heat at higher grain concentrations due to the increased thermal conductivity of the abrasive layer.

Keywords: Grinding, Temperature, CBN, Energy balance

1. Introduction

Inside the contact area of a grinding process, high temperatures are generated because of friction between the abrasive layer of the grinding wheel and the workpiece material as well as the involved plastic deformation during material removal. This induces a lot of heat into the workpiece which can alter its properties. Knowledge about the heat distribution during grinding is important for the development of process parameters, grinding tools and the adaptation of new cooling techniques. However, high cutting speeds and the presence of cooling liquids present a difficult environment for the integration of sensors into the grinding wheel. In previous approaches, the abrasive layer was segmented to allow for the integration of wire [1] or thin-film thermocouples [2,3], which increases the complexity of preparation. Recently, Brinksmeier et al. presented a new set-up to measure temperatures in the contact zone which uses infrared radiation via an optical fiber. This set-up can be integrated into conventional corundum grinding wheels [2,3]. It is integrated into the flange which still requires some modifications to the shape of the grinding wheel. In this paper, a new measurement device is presented which uses wire thermocouples for the temperature measurement but does not require any segmentation of the grinding wheel.

This device is described in the following section, as well as the experiments performed to evaluate the device during grinding. Based on experimental cutting investigations the influence of the grain concentration of the abrasive layer on the temperature of the grinding wheel was investigated.

2. Methodology

2.1. Temperature Measurement Device

The measuring device consists of a one-circuit board which is shown in Figure 1~~Figure 1~~ on the left side. It holds the CPU

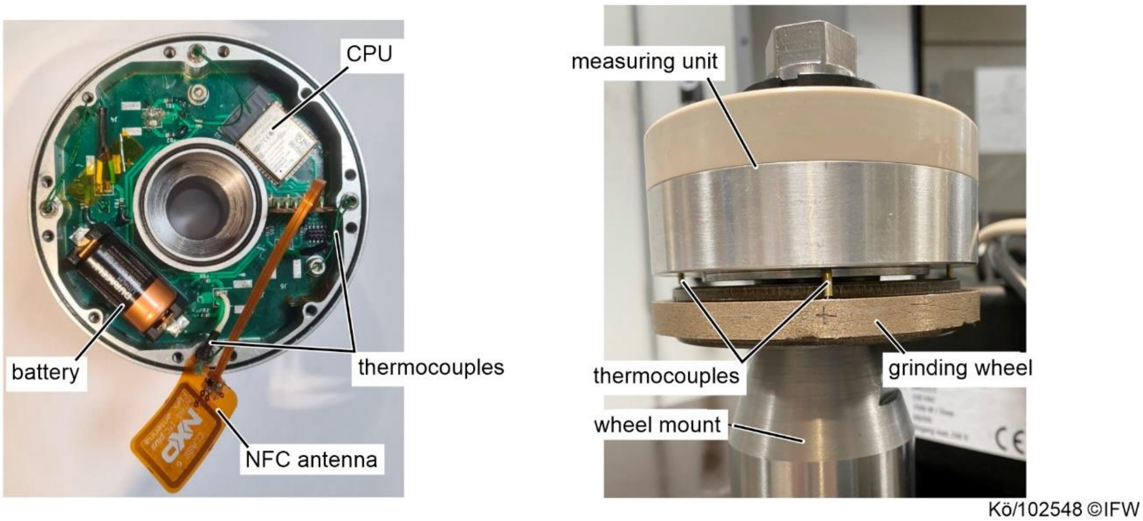


Figure 1. left: Circuit board of the measuring device. Right: Measuring device mounted on the grinding wheel.

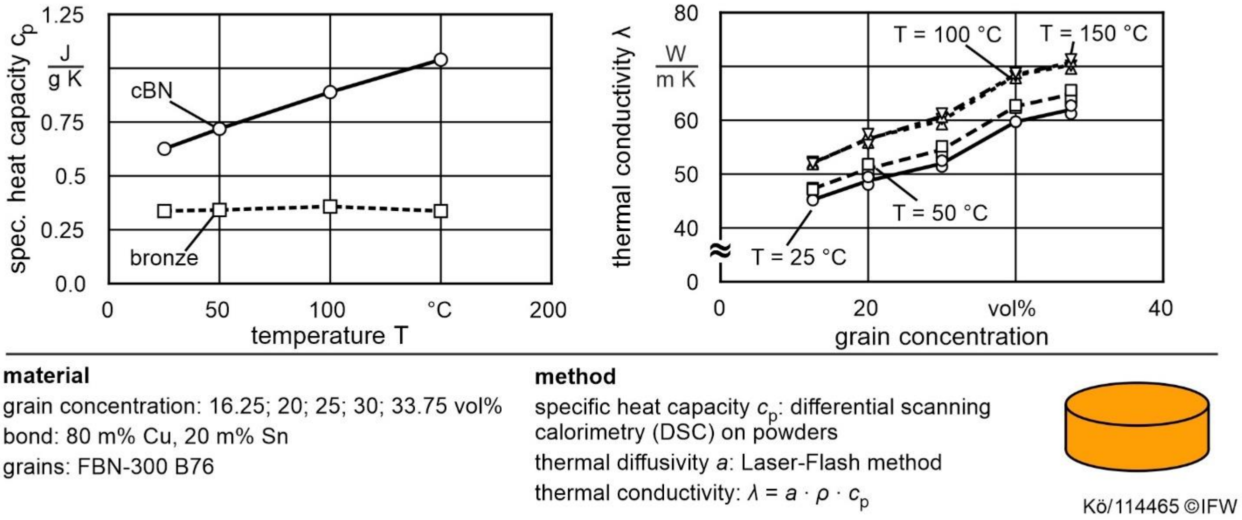


Figure 2. Thermal properties of the abrasive layer and its components.

(MCP9600) to collect and store the temperature data and handles the communication with external devices. The temperature data are recorded (sampling rate: 2 s^{-1}) and stored locally on the chip during a measurement because the high circumferential velocities (up to 20 m/s) during grinding disturb any wireless communication. After the experiment, the data can be downloaded wirelessly via a mobile phone. The device is powered by a battery, which is placed on the opposite side of the chip to balance the measuring device. For the temperature measurement, four thermocouples type K are soldered on the circuit board. To ensure fast reaction times the thermocouples have a diameter of 0.1 mm. This has the additional advantage, that the holes in the aluminum housing can be small as well, which hinders cooling liquids to enter the measuring device. Outside of the housing, the thermocouples are guided by copper pipes towards their measuring points on the grinding wheel. In the grinding wheel, two boreholes were drilled in the steel base of the wheel and another two were lasered into the abrasive layer with different radial distances. The thermocouples are inserted into these holes together with some thermal paste. For the grinding experiments, the measuring device and the grinding wheel are mounted on the same wheel mount (Figure 1~~Figure 1~~, right). The latter was specially designed and manufactured with an extended axis to be able to hold this structure.

2.2. Experimental setup

In a first step, static experiments were conducted as reference for the measurements during grinding. Therefore, a specimen (80 x 40 x 40 mm) of 20MnCrS5-steel (SAE 5120) was pre-ground up to generate a defined contact area. The grinding stroke with a depth of cut of 0.2 mm was interrupted in the middle of the workpiece which leaves the contact arc as it would be during grinding. Using a heating cartridge, the workpiece was heated to five different temperatures: 100, 120, 140, 160, 180 °C. After the specimen reached an equilibrium temperature, the grinding wheel was brought in contact with the ground contact arc and the temperature in the grinding wheel was measured for five minutes. These measurements were repeated at the same heating temperature with each thermocouple.

To study the temperature inside the grinding wheel during grinding, a face grinding process with a depth of cut of $a_e = 0.2$ mm, a feed velocity $v_f = 100$ mm/min, and a cutting speed $v_c = 20$ m/s was chosen.

The grinding wheels for these studies consist of a steel base and their abrasive layer is made of a tin bronze with 20 vol% tin (DIABRO 802040, by Dr. Fritsch Sondermaschinen GmbH) and cBN superabrasive grains (FBN300, by L.M. Van Moppes & Sons SA) with grain size B76 and in three different grain concentrations: 20, 25, 30 vol%.

2.3. Thermal characterisation of the abrasive layer

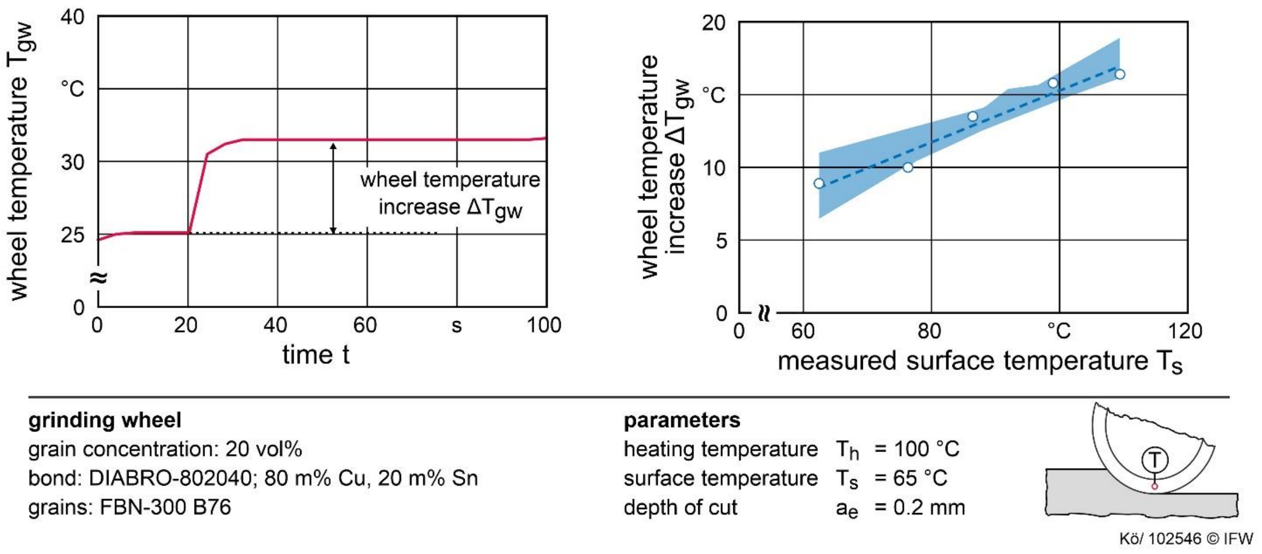
The thermal properties of the components of the abrasive layer were analysed beforehand because the thermal conductivity is a main factor for the heat flux between two bodies. Using differential scanning calorimetry (DSC), the specific heat capacity of the cBN-grains and the bronze powder was determined at four distinct temperatures between 25 – 150 °C as shown in Figure 2~~Figure 2~~. It can be seen that the heat capacity of the cBN-grains is higher compared to the bronze and increases with increasing temperature. This leads to the increased thermal conductivity of the compound material with rising grain concentration and temperature. The thermal conductivity λ was calculated using the following formula:

$$\lambda = a \cdot \rho \cdot c_p \qquad (1)$$

With: a = thermal diffusivity, ρ = density, c_p = specific heat capacity. The thermal diffusivity a was determined using the laser flash method at cylindrical specimens with five different grain concentrations (16.25, 20, 25, 30, 33.75 vol%) and for the same temperatures as the heat capacity. The density ρ of the specimen was measured using a density scale which takes advantage of the archimedean principle. The values for the thermal conductivity of the compound are lower compared to previously reported data for cBN. According to Rowe et al., the theoretical thermal conductivity for cBN is about 1300 W/(m K) and the effective thermal conductivity during grinding is 240 W/(m K) for cBN-grains in a vitrified bond [4]. On the other hand, the thermal conductivity of the compound is higher compared to bronze whose thermal conductivity is about 36 W/(m K) (for C90200, a copper alloy with a maximum 8 w% Sn) [5]. The thermal conductivity of the abrasive is therefore dominated by the properties of the bonding material and increased by adding more grains to the compound.

3. Results

First, the temperature increase during the static measurements is determined from the temperature profile as shown in Figure 3~~Figure 3~~. The temperature increase of the grinding wheel ΔT_{gw} is the difference between the equilibrium temperature when the grinding wheel is in contact with the heated workpiece and the temperature of the grinding wheel before contact. On the right side of Figure 3~~Figure 3~~, the temperature increase at different surface temperatures of the workpiece is exemplarily shown for a grain concentration of



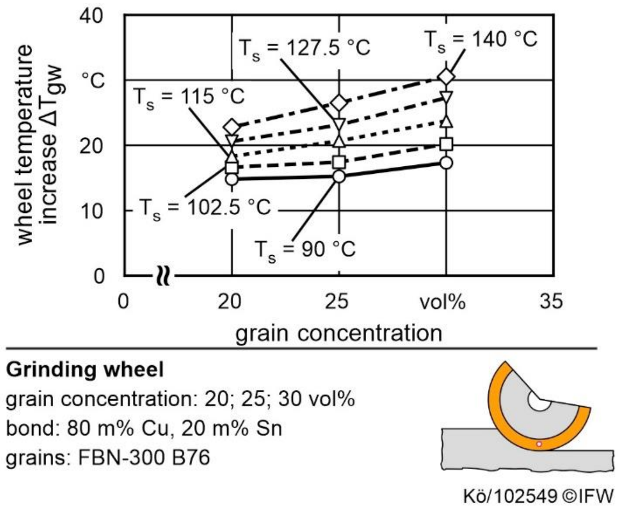
grinding wheel
grain concentration: 20 vol%
bond: DIABRO-802040; 80 m% Cu, 20 m% Sn
grains: FBN-300 B76

parameters
heating temperature T_h = 100 °C
surface temperature T_s = 65 °C
depth of cut a_e = 0.2 mm

Figure 3. Determination of the temperature increase inside the grinding wheel.

20 vol%. Besides some small fluctuations, the temperature increase of the grinding wheel is proportional to the measured surface temperature of the workpiece. Because of the open experimental system, the surface temperature fluctuates for different grinding wheels. For easier comparison, the temperature increase inside the grinding wheel was interpolated onto five equally distant surface temperatures between 90 and 140 °C for every grain concentration. Figure 5~~Figure 4~~ shows the increase of the temperature inside the abrasive layer of the grinding wheel for the different surface temperatures and grain concentrations.

While the temperature increase for a grain concentration of 20 vol% is slightly between 15 and 23 °C, the temperature increase in the grinding wheel with 30 vol% is between 17 and 31 °C. The mean temperature increase rises from 19 °C for 20 vol% up to 24 °C for 30 vol% grain concentration. The ability of the grinding wheel to take up heat from the workpiece increases not only with increasing grain concentration but also with increasing surface temperature. This behavior can be explained by the thermal properties of the abrasive layer and its components. The increasing thermal conductivity of the abrasive layer with temperature and grain concentration is the reason why the temperature of the grinding wheel rises as well with increasing grain concentration and temperature of the workpiece surface.

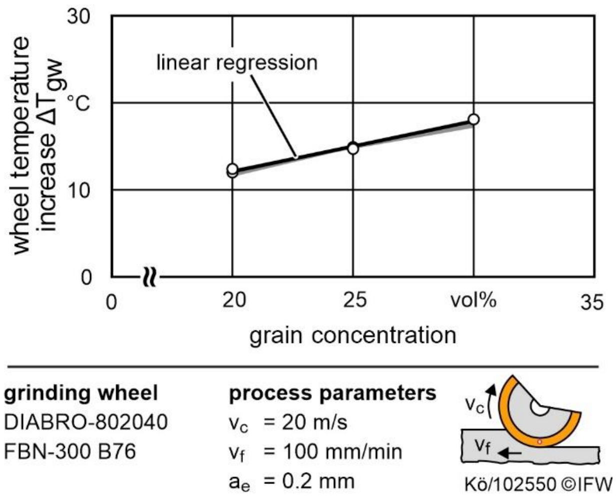


Grinding wheel
grain concentration: 20; 25; 30 vol%
bond: 80 m% Cu, 20 m% Sn
grains: FBN-300 B76

Figure 5~~4~~. Increase of the wheel temperature for different heating temperatures depending on the grain concentration.

A similar correlation was found between the temperature increase in the grinding wheel and the grain concentration during actual grinding. Figure 4~~Figure 5~~ shows the temperature increase inside the grinding wheel during grinding with oil cooling. The temperature of the grinding wheel increases linearly with an increasing amount of abrasive grains in the abrasive layer. A linear regression of the data from the dynamic measurements was performed which yields a slope of 0.58 ±0.03. This is in good agreement with the static measurements at 115 °C surface temperature. This is in good agreement with previous investigations of the energy partition for grinding with vitrified cBN wheels which found a maximum grinding zone temperature rise smaller than 120 °C [6]. This suggests, that in this case, the grain concentration has a small influence on the generated heat in the contact area but a high grain concentration takes up more heat and directs it into the grinding wheel, which reduces the heat flow into the workpiece.

4. Conclusion



grinding wheel
DIABRO-802040
FBN-300 B76

process parameters
v_c = 20 m/s
v_f = 100 mm/min
a_e = 0.2 mm

Figure 4~~5~~. Increase of the wheel temperature during grinding for grinding wheels with different grain concentrations.

This work presents a method to measure equilibrium temperatures inside a grinding wheel which requires only minimal preparation of the tool. Using the measuring device, the influence of the grain concentration on the thermal balance in bronze-bonded grinding wheels was investigated. It could be shown that the heat entering the grinding wheel increases with increasing grain concentration. This is a direct result of the high thermal conductivity of the cBN-grains. The grain concentration in the abrasive layer not only affects the grinding properties of the grinding wheel, but influences directly the heat balance of the grinding process. In future work, the influence of different cooling strategies, utilizing different combinations of oil and cryogenic cooling, on the thermal balance during grinding will be investigated as well.

Acknowledgment

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