Modeling analysis of temperatures at points in oxide film of grinding wheels

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Abstract. In this work, a temperature at points model of the abrasive grains in ELID grinding is presented for the analysis of the temperature of single cutting grain between the workpiece and the oxide film on the ELID wheel surface. The corresponding calculation results show that temperature of single grinding point is significantly higher than the average temperature through the grinding zone.

1. Introduction

Most temperature models of grinding are based on the assumption that grinding process is conducted by zonal heat sources. The average temperature of the entire grinding area then can be obtained by integral operation [1]. But these methods are limited only to local area and are often not suitable to illustrate changes in temperature for single grinding grain and its surrounding area.

The formation and transition of oxide films in grinding process is dependent upon grinding temperatures, especially upon temperature around a single abrasive grain. More iron oxides convert into α-Fe2O3 in oxide films under the effect of the high temperature around the abrasive grains, which comes up to or excess to transition temperature [2].

To better assess the formation and transition of α-Fe2O3 around abrasive grains, we need data that reflect the temperature distribution around the grains measured in an accurate way. However, speed of grinding wheels is relatively high for plain grinder. Thermometry, such as thermocouples and IR temperature measurement technology, has been reported [3], but to the best of our knowledge, their sub-millisecond response time cannot fully satisfy the measurement require for temperature at point on the single grain. Here we present a theoretical study on temperature-at-point model in grinding process, for obtaining reliable prediction on temperature distribution around abrasive grains.

2. Flash Temperature Modeling

Taking the temperature as the performance, the grinding power per unit time is given by:

\[ P = F_t V_s \]  

(1)

where \( P \) is the total grinding power, \( F_t \) is the tangential grinding force, and \( V_s \) is the grinding velocity. According to the grinding theory, the total grinding power is contributed by the workpiece, chips, and the abrasive wheels. Then the other arguments are given by

\[ P = P_{\text{work}} + P_{\text{wh}} + P_{\text{chip}} \]  

(2)
where \( P_{\text{work}} \) is the grinding power contributed to the workpiece, \( P_{\text{wh}} \) is the grinding power contributed to the grinding wheels, and \( P_{\text{chip}} \) is the grinding power contributed to the chips. Assumed \( V \) is the volume of chips removed per unit time, and the corresponding grinding power contributed to the chips is given by

\[
P_{\text{chip}} = V \rho c \theta_{\text{chip}}
\]

where \( \rho \) is density of the chip, \( c \) is specific heat of the chip, and \( \theta_{\text{chip}} \) is the temperature rise of the chip.

The grinding power is consequently contributed to the grinding wheels and the workpiece, except the partially to the chips. Assuming that the number of actual contacting grains and cutting grains in the grinding area is \( N \), and the individual heat sources between the abrasive grains and the workpiece, is considered as a circular disc as shown in Figure. 1. The grinding power for each cutting grain is given by

\[
P_{\text{contact}} = \frac{P - P_{\text{chip}}}{N}
\]

where \( P_{\text{contact}} \) is the grinding power in contact area between the abrasive grains and the workpiece.

\[\text{Figure. 1 Schematic of a circular disc heat sources in grinding}\]

The theoretical number of contacting grains in the grinding area \( N_0 \) is given by

\[
N_0 = 6 V_g / \pi d_g^2
\]

where \( V_g \) is the volume ratio of the grains to the wheel surface, and \( d_g \) is the grain radius. Thus, the effective number of the contacting grains per unit area, \( N_{\text{cont}} \), is given by

\[
N_{\text{cont}} / N_0 = (d_g - d_b) / d_g
\]

where \( d_b \) is the average diameter of peeling-off grains.

\[\text{Figure. 2 Schematic of the actual contacting grains in the grinding zone}\]

The range of diameters of the actual contacting grains is represented as \( d_g - d_b \), covering from the maximum sizes to the minimum size of the grains for ELID grinding wheels, as shown in Figure. 2. The cutting time of the grains, \( t_1 \), is given by
where \( l \) is arc length of contact area. The time of contact of any point at the contacting interface on the workside, \( t_2 \) is given by

\[
t_2 = \frac{2r_0}{V_s}
\]

Equation (8)

where \( r_0 \) is the radius of the circular area between the grains and the workpiece.

We obtain the energy density of the contact circular as

\[
p_{\text{wt}} = \frac{P_{\text{circular disc}}}{A_{\text{circular disc}}}
\]

Equation (9)

where \( A_{\text{circular disc}} \) is the area of the contact circular.

Referring to the heat sources model [4],

\[
\theta = \frac{P_{\text{wt}}}{k_2} \left[ \frac{4\alpha t}{\pi} e^{-\frac{\pi^2}{4\alpha t}} - 4\alpha t \right]
\]

Eq. (11) represents the grinding temperature between the grains and the workpiece. The energy of the circular transfers to both the workpiece and the abrasive grains. Similarly, to obtain the grinding temperatures on the grain side, we need to know the heat partition fractions for the workpiece and the abrasive grain. For the grains:

\[
\theta_1 = \frac{B_1 P_{\text{wt}}}{k_1 \sqrt{\pi}} \sqrt{\frac{4\alpha_1 t_1}{\pi}}
\]

For the workpiece:

\[
\theta_2 = \frac{B_2 P_{\text{wt}}}{k_2 \sqrt{\pi}} \sqrt{\frac{4\alpha_2 t_2}{\pi}}
\]

where \( \theta_1, \theta_2 \) are temperatures of the grains and the workpiece, respectively. \( B_1, B_2 \) are the heat distribution coefficient from heat sources to the grains and to the workpiece, respectively. \( \alpha \) is the corresponding heat diffusion coefficient, \( k \) is the corresponding heat conductivity, and \( t \) is the corresponding contact time for the grains and the workpiece.

Since \( \theta_1 = \theta_2 \) at the interface of contact, we obtain

\[
\frac{B_1 P_{\text{wt}}}{k_1 \sqrt{\pi}} \sqrt{\frac{4\alpha_1 t_1}{\pi}} = \frac{B_2 P_{\text{wt}}}{k_2 \sqrt{\pi}} \sqrt{\frac{4\alpha_2 t_2}{\pi}}
\]

We can simplify Eq. (14) by \( B_2 = 1 - B_1 \), thus,

\[
B_1 = \left[ \left( 1.46 t_1 / k_1 \right) + \left( 1.46 t_2 / k_2 \right) \right]^{-1}
\]

Using Eq. (15), the heat partition fractions for the abrasive grains and the workpiece can be calculated. Substituting Eq. (15) to Eqs. (12)-(13), temperatures for the abrasive grains and the work can be obtained, and are referred as instantaneous contact temperatures, as well as flash temperature or point temperature in grinding. And the Eqs (12)-(13) are referred as the flash temperatures model of the contacting grains.

3. Results And Discussion

Parameters in the flash temperature model are shown in Table 1 and Table 2. And the results are depicted in Figure. 3.
Temperatures at grinding points as a result of calculation are determined to be higher than the average temperature of grinding zone [5]. The oxide films of ELID grinding wheels are in high temperature surrounding, making them more easily dehydrated and having tendency to convert their chemical composition. Heat energy of lattice water and adsorption water, which absorbed in the oxide films coated around the abrasive grains, are $10^{-6}$J and $10^{-5}$J, respectively, far less than cutting heat. The cooling effect on single abrasive grain is negligible, which is coincident with plain grinding, and can be ignored. It demonstrates that cutting fluid is hard loaded into the cutting area, and hence, temperatures around the abrasive grains cannot be cooled down efficiently. However, only a small amount of the abrasive grains for the whole grinding zone participate in the grinding [6]. The majorities of the abrasive grains may not actually contact with the workpiece. Some may only rub or plough. Consequently, other area except the actual cutting grains covered with the oxide films. And the oxide film is actually contacting with the workpiece at these area, with adsorbed water and lattice water’s effective cooling on the grinding zone. Hence, the adsorbed water and the lattice water within the oxide film are estimated to distinctly absorb the grinding heat and lower the temperature through the grinding zone.
4. Conclusions

A temperature at points model of ELID grinding is proposed in this paper based on grinding heat distribution and the grinding temperatures around the abrasive grains. The corresponding results are performed below:

(1) This thermal model considers the grinding heat partition and temperatures of the abrasive grains. Data demonstrated that temperatures of the abrasive grains were significantly higher than the average temperature at the grinding zone, which enables to theoretically explain the composition transition of the oxide films in ELID wheels.

(2) The dynamic cooling effect of the oxide films in the contact temperatures was also presented. It predicted that the grinding heat was barely reliable to cool down, while the cooling effect of the oxide films on the abrasive grains can be neglectful. However, the average temperature at the whole grinding zone can be chill-down with the effort of the oxide films coated on the grinding wheels.

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