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MODELING AND SIMULATION STUDIES ON TEMPERATURE FIELD IN MICRO END GRINDING

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ABSTRACT

A significant machining method-Micro End Grinding (MEG), is used for micro parts made of hard and brittle materials in this paper. As an important parameter of the grinding process, the grinding temperature is closed to the machined surface quality and the grinding wheel wear, etc. In order to research the influence of the temperature field on MEG, the mechanism of machining process is analyzed and the finite element model of the micro end grinding temperature field is established. Based on this model, the finite element simulation experiment is conducted. From the results it can be found that a similar circular ring temperature field is forming in the grinding process of MEG. The highest surface temperature of workpiece is in the center of wheel end face. The temperature gradient increases when the workpiece surface of different position is closer to the center of wheel end face in both the direction of x and y axis. During the period when the wheel approaches and leaves the workpiece edge, the surface temperature of the workpiece edge will be higher relatively than other workpiece surface because of the heat accumulation due to workpiece boundary.

KEYWORDS

Grinding temperature, heat flux, FEM, hard and brittle materials

1. INTRODUCTION

Based on a study, expanding requirements of microproducts with features and structures at micro-scale and nano-scale, such as micro optical system, micro robot, micro motor, fuel injection nozzle, presents stimulation and challenges to micromachining technology [1,2]. Machining of micro parts made from nonferros metals and other materials, which are not different to machine, can be reliably achived by microturning, micromilling and microdrilling, and so on. However, as to 3-D micro components of hard and brittle materials, microgrinding is the most important processing technology.

Nevertheless, the temperature as one of the important machining parameters in the micro end grinding will cause thermal cracking, thermal residual stress and tool wear [3]. Hence, it is extremely important for modeling and simulation of the grinding temperature field.

A researcher studied the three-dimensional finite element model in surface grinding and simulated the temperature distribution of the workpiece in different cooling conditions [4]. A group of researchers researched the temperature distribution on the workpiece and analyzed the grinding heat transfer of Quartz [5]. On the basis of the mathematical model of intermittent grinding temperature field and integral solution formula, a researcher simulated the ordinary grinding and intermittent grinding temperature field using VC ++ programming language [6]. A study showed the cup wheel grinding temperature field, established a simplified mathematical model of grinding the rectangular workpiece, 45 # steel, by arc moving heat source and obtained the inside temperature distribution of it using ANSYS [7]. However, the micro end grinding temperature field has not been researched so far.

In this paper, in order to research the influence of the temperature field to MEG, the mechanism of machining process of MEG is analyzed. Based on J. C. Jaeger's moving heat source theory, the heat flux model is developed theoretically and then the finite element model of temperature field is established. Basing on the models above, the finite element simulation experiments are conducted. Then, the mechanism of grinding temperature field distribution is investigated basing on the simulation results.

2. MECHANISM OF MACHINE PROCESS

Figure 1 shows the machining process of MEG. The precision feed of grinding wheel vw is in the direction of x-axis. Meanwhile, the grinding wheel rotates at high speed ns around the z-axis, which orients in cutting depth direction.

The material is removed mainly due to the interaction between abrasives on wheel end face and material in grinding zone. The abrasives on outer rings contact with unmachined material firstly and play the role of cutting. Those on inner rings mainly slide, plough and repeatedly iron the machined surface. Grinding heat in the process of MEG is produced by the interaction between both the outer and inner abrasives on wheel end face and the workpiece materials. Because of the different effect of abrasives in outer rings and inner rings, the grinding temperature field will have the different influence on workpiece surface.

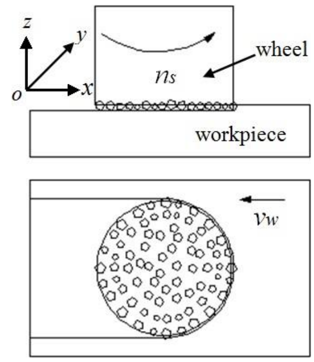


Figure 1: Machining process of MEG.

3. THEORETICAL CALCULATION HEAT FLUX

Based on Fourier heat conduction law and J. C. Jaeger's moving heat source theory, the theoretical analysis of the grinding temperature field is conducted as follows.

The grinding power measured by grinding can be expressed as:

$$P = \frac{M_z n_s}{9550}$$

Where M_Z is the axial torque; n_S is the wheel rotation speed.

The outer and inner abrasives on wheel end face are contacting the workpiece materials in the process of MEG, so the total heat flux q_t can be simplified to a uniform model which is expressed as follows:

$$q_t = \frac{M_z n_s}{9550\pi R^2} \quad (2)$$

The grinding heat transfers to the wheel, workpiece, chips and surrounding air. However, the heat transferring into chips and air is limited enough to be neglected. Hence, the total heat flux in the grinding zone can be expressed as follows:

$$q_t = q_w + q_s \quad (3)$$

Where q_W is the heat flux of the workpiece; q_S is the heat flux of the wheel.

Grinding heat distribution ratio R_W is the ratio of heat transferring into workpiece and total heat in the grinding zone. Currently, there are three main models about R_W. In several researches, there exists a tremendous difference between the theoretical calculation result and experimental result of the distribution ratio for grinding hard and brittle materials; The distribution ratio models are mainly used for grinding metal materials, so these models are not suitable for machining hard and brittle materials; The distribution ratio model is mainly used in dry grinding for ceramics and other brittle materials [8-11]. Therefore, it is introduced to this paper, which can be expressed as follows:

$$R_W = 1 - \frac{2j(\theta_a - \theta_0)\sqrt{\pi} B^2}{F_x v_s \sqrt{\tau_0}} \quad (4)$$

Where j is the heat storage coefficient; θ_0 is the uniform temperature of abrasive; θ_a is the end surface temperature of instantaneous abrasive; B is the assumed cylindrical abrasive radius; F_x is the grinding force; τ_0 is the grinding time.

In this work, the distribution ratio is determined to be 0.8, according to Wang's research [11]. Therefore, by the Equations 2-4, the heat flux of the workpiece q_W can be expressed as:

$$q_w = \frac{0.8 M_z n_s}{9550\pi R^2} \quad (5)$$

4. FINITE ELEMENT MODEL OF GRINDING TEMPERATURE FIELD

Based on the law of conservation of energy and the fact that the grinding process is transient, the mathematical model of transient temperature field can be built using the finite element theory. The heat conduction equation of grinding temperature field is as follows：

$$pc\frac{\partial\theta}{\partial t} - \frac{\partial}{\partial x}\left(k_x\frac{\partial}{\partial x}\right) - \frac{\partial}{\partial y}\left(k_y\frac{\partial}{\partial y}\right) - \frac{\partial}{\partial z}\left(k_z\frac{\partial}{\partial z}\right) - \rho Q = 0$$

(In the α) (6)

Where α represents the entire domain, which consists of three types of boundary conditions, that is:

$$\theta = \theta^* \quad (\text{boundary } \Gamma_1) \quad (7)$$

$$k_x\frac{\partial\theta}{\partial x}n_x + k_y\frac{\partial\theta}{\partial y}n_y + k_z\frac{\partial\theta}{\partial z}n_z = q \quad (\text{boundary } \Gamma_2) \quad (8)$$

$$k_x\frac{\partial\theta}{\partial x}n_x + k_y\frac{\partial\theta}{\partial y}n_y + k_z\frac{\partial\theta}{\partial z}n_z = T(\theta_a - \theta) \quad (\text{boundary } \Gamma_3) \quad (9)$$

here d is the density of the material; c is the specific heat; k_x, k_y, k_z is the thermal conductivity in the x, y, z direction; $Q=Q(x,y,z,t)$ is the density of the heat source inside the object; n_x, n_y, n_z is the direction cosine for the boundary of outward normal; $\theta=\theta^*(\Gamma,t)$ is the given temperature of the boundary; $q=q(\Gamma,t)$ is the given heat flux of the boundary; T is the convective heat transfer coefficient; $\theta_a=\theta_a(\Gamma, t)$ is the external environment temperature under natural convection conditions; t is the time.

Considering the grinding depth is very small, the grinding surface and the workpiece surface is assumed to be in the same plane. The entire boundary of the workpiece is constituted by the boundary of $\Gamma 1$ and $\Gamma 2$. $\Gamma 2$ is determined by the position of the moving heat source. Substituting into the boundary conditions, the finite element mathematical model of dry grinding can be expressed as follows:

$$\int_{\alpha^e} \rho c N_i N_j T d\Omega + k\int_{\alpha^e}\left(\frac{\partial N_i}{\partial x}\frac{\partial N_j}{\partial x} + \frac{\partial N_i}{\partial y}\frac{\partial N_j}{\partial y} + \frac{\partial N_i}{\partial z}\frac{\partial N_i}{\partial z}\right)T d\Omega = \int_{\Gamma_2^e} q N_i d\Gamma \quad (10)$$

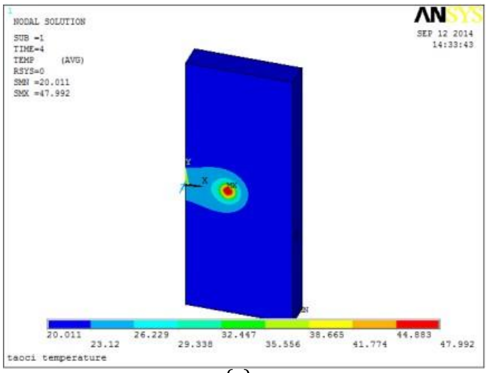
5. RESULTS AND DISCUSSION OF FINITE ELEMENT SIMULATION

Basing on the finite element model developed above and ANSYS software, the simulation experiments are conducted at the grinding conditions: wheel speed n_S of 18000r/min, workpiece speed v_W of 0.1mm/s and grinding depth a_p of 1μm. Using the ANSYS program's Thermal module by modeling, meshing, loading, solving and post-processing, the micro end grinding temperature field can be obtained. Due to the finite element software can not load moving heat source, so this process is discrete. A fixed heat loads in a grinding zone with a short time. And then, the fixed heat moves to the next grinding zone and the last obtained result regards as the initial conditions. Therefore, the moving heat source is achieved by APDL programing in this paper. Wheel radius is 1.5mm. The alumina ceramics sample's size is 50×20×5mm, of which the thermal parameters are shown in Table 1.

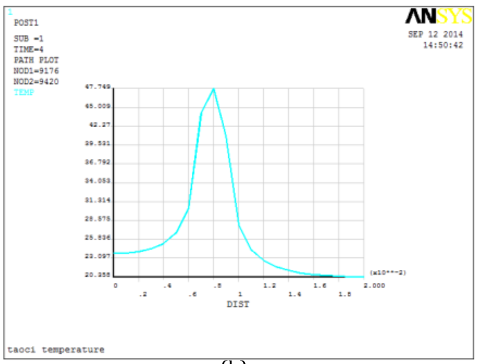
Table 1: Thermal parameters of the material.

c（J/（kg.k)）	ρ（kg/m^3）	k（W/kg.k)
750	3750	25

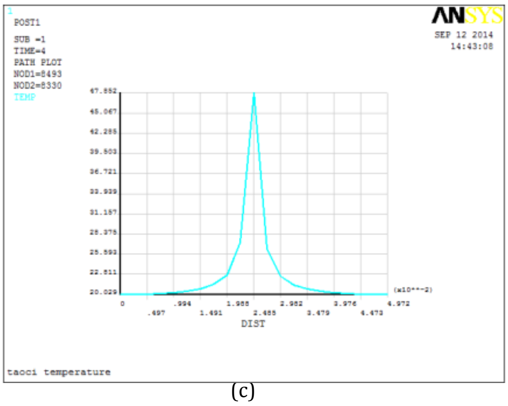
The simulation diagrams of micro end grinding temperature field are shown in Figures 2 and 3:



(a)



(b)



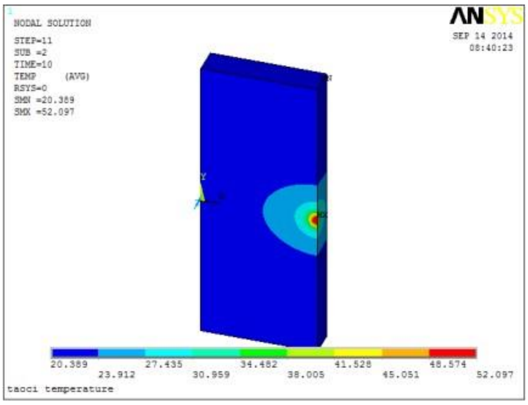
(c)

Figure 2: (a). Nephogram of the temperature field, (b) Temperature profile in x direction, (c) Temperature profile in y direction.

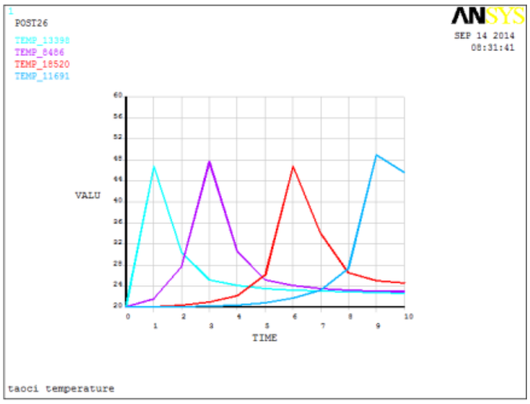
Figure 2(a) shows that the grinding temperature field of MEG is not distributed homogeneously and formed to be similar circular rings. Because the abrasives in outer rings and inner rings have different effect in the process of MEG. Apparently, the workpiece surface contacting with the inner abrasives will be impacted much than that of the outerabrasives. The surface temperature of the workpiece far away enough from the wheel end face remains unchanged, hence the center of the wheel end face will have a greater impact on the surface quality.

Figure 2(b) shows that the temperature curve of the different position of workpiece surface along the x direction. the closer the position of workpiece surface to the wheel face, the greater the temperature gradient is. The maximum temperature in the wheel end faceis about 47.75°C.

Figure 2(c) shows that the temperature curve of the different position of workpiece surface along the perpendicular direction of the feeding direction. The surface temperature of the workpiece becomes a symmetrical distribution and the maximum temperature is in the center of wheel end face. The temperature gradient is also great.



(a)



(b)

Figure 3: (a) Nephogram of the temperature field in workpiece edge , (b) The temperature curve of four different positions in wheel surface.

Figure 3(b) shows the temperature curves of four different positions in wheel surface. The first three temperature curves represents for three given position of workpiece surface. As the wheel moves to a point which is of a certain distance to it, the temperature starts rising. When the center of wheel end face moves above the given position, the temperature approaches to the maximum value. And then, it decreases to the initial temperature gradually as the wheel passes. The blue one is the temperature curve when the wheel approaches and leaves the workpiece edge. Obviously, the maximum temperature is higher than others, which can be seen from Figure 3(a).The reason for this phenomenon may be that the heat transfer space reduces and the grinding heat accumulates. The heat can not be quickly transferred to the surrounding space. Therefore, the surface temperature will be higher than others.

6. CONCLUSION

In this paper, the micro end grinding temperature field is theoretically and experimentally studied by the finite element method. It can be concluded from this study that:

(1) The heat flux model and the temperature field finite element model in MEG are developed. Corresponding simulation experiments are conducted. Then, mechanism of grinding temperature field is analyzed.

(2) A similar circular ring temperature field is formed around the wheel end face in the process of MEG. The highest surface temperature of workpiece is in the center of wheel end face.

(3) The temperature gradient increases when it is closer to the center of wheel end face in both the direction of x and y axis.

(4) Because the heat transfer space reduces and the grinding heat accumulates, the surface temperature is increasing abruptly when the wheel approaches to the workpiece edge.

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