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Finite Element Simulation of SiC Ceramics Grinding with Single Diamond

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ABSTRACT: To explore the mechanism of silicon carbide ceramic cutting with single grain, simulation is carried out on silicon carbide ceramic cutting with single diamond grain. Based on the ABAQUS finite element analysis software, the constitutive model of the material is established. The single grain linear cutting simulation is modeled by finite element method and the phenomena is analyzed for stress changes and distribution. The results show that fluctuations are existed in stress and cutting force. When the contact between the abrasive and the workpiece surface occurs, the local radial stress nephogram is formed in the material, and the equivalent force is smaller and decreases gradually from the contact region to the interior of the material.
Keywords: single grain; Silicon carbide ceramic; finite element simulation; stress distribution

I. INTRODUCTIION

Silicon carbide ceramic is a kind of engineering ceramics, with high hardness, high wear resistance, low density, corrosion resistant properties and high brittleness. It has been widely used in the fields of industry, optics, aerospace and automobile, and grinding has become its main processing method. Grinding is usually used as the last step in processing parts, and it is the most widely finishing technology at present. Its processing essence is a large number of discrete abrasive particles distributed on the surface of the grinding wheel and interacting with the processed materials so as to achieve the material removal[1,2]. Because in the grinding process, the number of the abrasive particle is large and the influence of various factors is obvious, such as cutting edge shape, size, position and angle and process parameters, these make it difficult to study the mechanism of material removal in grinding process[3]. In order to study the mechanism of grinding intensively, the research ideas of the part to the overall should be followed. Based on the research of single abrasive grinding, the grinding results of single abrasive particles are integrated in the grinding area to explain the phenomena in the grinding process[4]. The research of single grain grinding mechanism is an important method to realize the mechanism of complex abrasive machining. The grinding process is complex and it is difficult to carry out a comprehensive experimental measurement and observation. Therefore, it is necessary to use finite element simulation to predict the phenomena in the grinding process effectively. At present, scholars at home and abroad have done a lot of research on the simulation of finite element[5] and molecular dynamics[6]. Komanduri uses the molecular dynamics to simulate the indentation and scratch process of alumina single abrasive particle, and analyzes the anisotropy of material hardness and coefficient of friction[7]. Yu Siyuan uses the theory of molecular dynamics to simulate the static indentation of monocrystalline silicon in ultraprecision grinding and dynamic grinding process of single abrasive particles, and then analyzes the influence of cutting depth and radius of tool nose on grinding force and cutting temperature[8].

Feng uses the finite element analysis to construct the model of grinding force in grinding of ceramic materials, based on the analysis of the distribution of diamond abrasive grains and the thickness of micro debris[9]. Zhu Dahu simulates the cutting process of single abrasive particle according to the generation and the expansion of SiC grinding crack, and points out that when the maximum un-deformed cutting thickness is less than 0.29 μm, the material removal is dominated by plastic domains. When it is larger than 0.3 μm, the material removal is dominated by brittleness domains and there is a crack[10].This paper is based on the Drucker-Prager hard brittle material constitutive model, and the grinding process of SiC ceramics with single diamond abrasive grains is simulated by ABAQUS finite element software, and then the change and distribution of stress and the change of cutting force during grinding are analyzed.

II. GRINDING SIMULATION OF SINGLE ABRASIVE GRAIN

2.1 Geometric model of single abrasive grinding

Although in actual grinding process, the tools and workpieces belong to bevel grinding in most cases, in theoretical and experimental research, orthogonal grinding is more common, so orthogonal grinding model is adopted[11]. The simplified model of single diamond tool in finite element model adopts a two-dimensional geometric model with a top cone angle of 136 degrees. Due to the hardness and strength of diamond, the hardness and intensity of SiC ceramics vary greatly, and the diamond almost does not deform during the grinding process, therefore the abrasive particles can be simplified as analytical rigid bodies, and the SiC ceramic workpieces are considered as deformable bodies. In order to avoid strain concentration, improve calculation accuracy and save computation time, proper mesh generation is very important. The mesh is divided by the linear reduced integration unit, the seeds are set in length and height by Seed Edge By Number, and the density deviation coefficient is set in the height direction. This ensures that the mesh area in contact with the diamond tool is finer and the mesh area in the region far away from the tool is relatively sparse. The mesh is shown in figure 1. When diamond grit is meshed, considering that diamond is a rigid body and the deformation in simulation process is small, so the diamond grit is divided by the free mesh method, and the element use CPE3 triangular elements. The mesh is shown in figure 2.

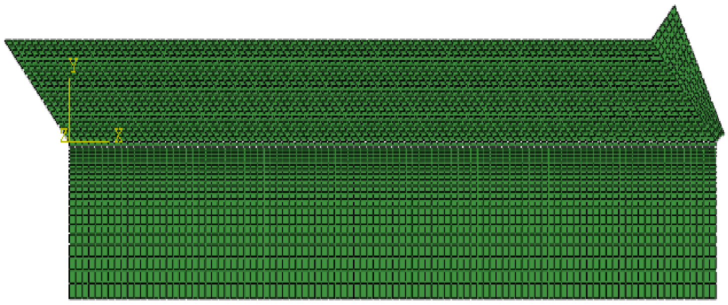

Figure 1 Mesh generation of workpiece finite element method

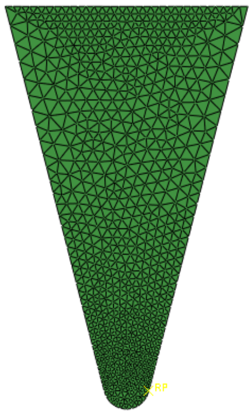

Figure 2 Mesh generation of diamond grit finite element method

2.2 Simulation model of grinding process for single abrasive particle

The elastic modulus and yield strength of diamond grains is much greater than that of SiC ceramics, and the diamond abrasive deformation in grinding process is very small, so in order to reduce the time used for explicit analysis, the wear and deformation of diamond grits can't be considered and the diamond grits can be considered as rigid bodies. The material performance parameters are shown in table 1. As a typical hard brittle material, SiC ceramic is easy to break. The ABAQUS is a continuum and no fracture phenomenon will occur during the finite element analysis, so in order to analyze the stress changes, SiC ceramic can be considered as a plastic material before the fracture. And the JH-2 constitutive model[12] is adopted. The material performance parameters are shown in Table 2. The simulation model of the tool and the workpiece is shown in figure 2.

Table 1 Material property parameter of diamond

Material	Density/ $g \cdot cm^{-3}$	Modulus / GPa	Poisson's ratio
Diamond	3.50	1140	0.20

Table 2 Constitutive model parameters of SiC ceramic materials

Parameter	Value
Modulus（N/m^2）	420×10^9
Density（kg/m^3）	3250
Poisson's ratio	0.14

Initial yield stress（N/m^2）	12.5×10^9
Friction angle（°）	13
Expansion angle（°）	-5
K	0.92

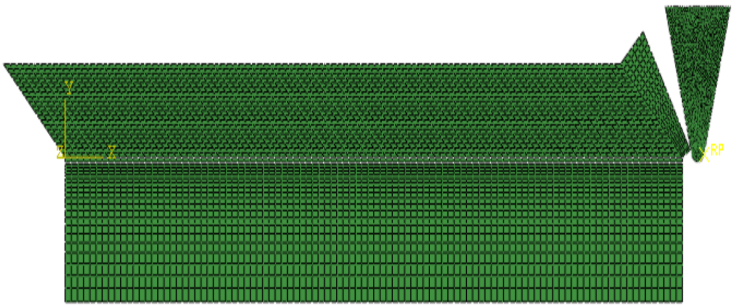

Figure 3 Assembly drawing of tool and workpiece

In the actual process of grinding, the abrasive particles are rotating to grind the workpiece, but the cutting depth of abrasive grains is much smaller than the contact arc length between abrasive particles and workpiece, so the motion of a single abrasive particle can be approximately linear in a very short period of time. Moreover, the speed of the workpiece is much smaller than that of the abrasive particle, so the workpiece position can be assumed to be stationary and the grinding process of a single abrasive particle can be simplified as a linear motion model. As a rigid body, the degree of freedom of the displacement and rotation of the other direction in addition to the displacement of the X axis are applied to the abrasive particles as a whole, and the constraint of the degree of freedom of all directions is applied to the bottom and left sides of the workpiece.

III. SIMULATION RESULTS AND ANALYSIS OF SINGLE ABRASIVE GRINDING

The stress distribution of the silicon carbide ceramic workpiece is shown in Figure 4. When the contact between the abrasive and the workpiece surface occurs, the local radial stress nephogram is formed in the material, and the equivalent force is smaller and decreases gradually from the contact region to the interior of the material. The maximum stress is in the region of contact with the tool and the maximum is 6.585×10^{11} MPa. The more away from the tool, the smaller the stress value. In the initial stage of cutting, elastic deformation occurs on the workpiece surface. Plastic deformation occurs on some of the material with the increase of time, and the typical behavior of this plastic or permanent deformation is the accumulation of material at the front of the particle. Finally, as time increases further, the chip is formed from the surface of the workpiece.

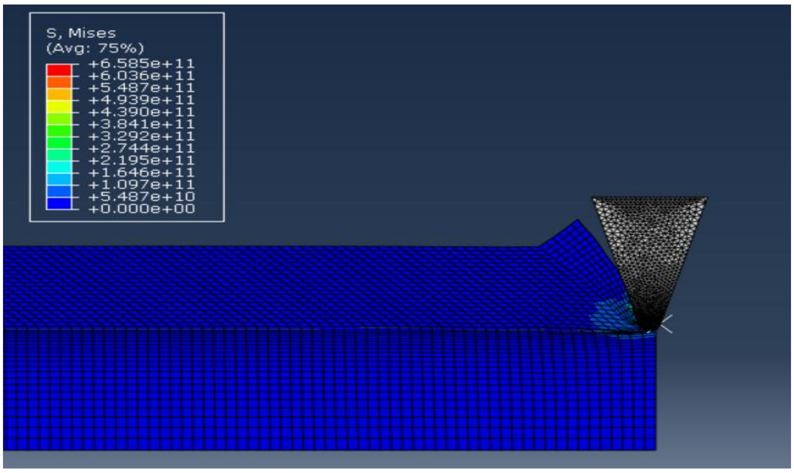

Figure 4 Drawing of equivalent stress distribution

IV. CONCLUSION

1. The maximum stress is in the region of contact with the tool and the more away from the tool, the smaller the stress value.
2. In the initial stage of cutting, elastic deformation occurs on the workpiece surface and with the increase of

time plastic deformation occurs on some of the material.

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