Simulation Study on CBN Wheel Wear of Ultra-high-speed Grinding

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Abstract. In this paper, true shape of the grinding wheel abrasive particle was simulated and the wear model of single CBN abrasive particle was established based on smoothed particle hydrodynamics (SPH). Not only the wear process of CBN abrasive particle but also the effect of grinding process parameters on the wear of grinding wheel particle, such as speed of grinding and feed rate were simulated. Moreover, to draw the conclusion of the wear of grinding wheel, orthogonal simulation experiment results were compared with the existing experimental data which proved that they are basically the same.

1. Introduction

Ultra-high-speed ceramic CBN grinding has become the development trend of grinding technology because of its many advantages [1]. However, the main factor that restricts its development is the research of grinding wheel wear rules [2]. In the past, many scholars and scientific research institutions used physical experiments to study the mechanism and rules of wheel wear, such as Northeastern University, Hunan University, Zhengzhou Research Institute for Abrasives & Grinding. But to achieve above, it not only will cost a great deal of manpower and material resources but also will be a spectacular waste of resources.

Therefore, this paper adopts a method of numerical simulation to simulate the wear situation of ceramic CBN grinding wheel under different working conditions by using ANSYS/LS-DYNA software to carry out the wear rate and wear rules, which can be used to guide practical operation and reduce the wear of the grinding wheel.

2. Study on wear mechanism of ceramic CBN grinding wheel

2.1 Wear mechanism of single abrasive particle.

The wear process is virtually the process of numerous abrasive particle wear. In grinding process, the cutting depth of abrasive particles firstly increases from zero to maximum, then gradually decreases to zero, finally separates from the workpiece. In this process, the deformation and removal of the material pass through three phases: scratching, ploughing and chip cutting, meanwhile, the abrasive itself is also affected by extruding, rubbing and impacting of the workpiece material, resulting in three types of wear patterns [3], such as the friction and wear of the grinding wheel, the crushing of abrasive particles and the wear out of the abrasive particles.

2.2 Wear mechanism of CBN grinding wheel.

According to large number of physical experiments and literatures around the world, it is pointed out that there are many types of abrasive particle wear on grinding wheels, but the main wear can be divided into two types which are abrasion wear and crushing wear [4]. Thereinto, abrasion wear accounts for 40% or more, which is the main reason why abrasion wear was simulated in this paper.

3. Modeling of worn abrasive particles on CBN grinding wheel

In the process of studying the wear of CBN grinding wheel, the modeling of abrasive particles is one of the most critical steps, which is also one of the determining factors of whether the simulation result can reflect the abrasive wear in the actual process.

In the initial simulation of grinding or wear process, the geometry of abrasive particles is usually modeled by simplified geometry, when the geometric characteristics or processing characteristics of the abrasive particles are considered as shown in Fig.1 [5].

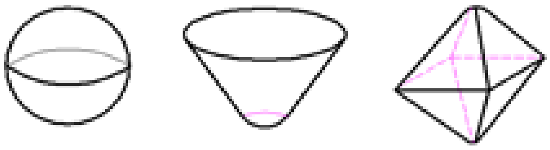


Fig. 1 Wear abrasive model in early phase

The use of the sphere is because of the abrasive particles negative front angle processing characteristics [6]. The cones and octahedrons are designed to simulate the top shape of the abrasive particles [7]. Although it can simplify the model and simulation process resulting saving simulation time, it can't really reflect the irregular shapes of the actual particles. Therefore, this paper will establish irregular abrasive particles based on the existing model to simulate the wear process.

D. V. De. Pellegrin, G. W. Stachowiak et al. [8] invented the use of random cut octahedrons to obtain irregular abrasive bodies in 2004, and through theoretical analysis to conclude that such abrasive models conform to the grinding process. Therefore, this method was adopted in this paper. First, an octahedron was built using three-dimensional software, as shown in Fig.2. Then a random plane was created to cut the octahedron. as shown in Fig.3.

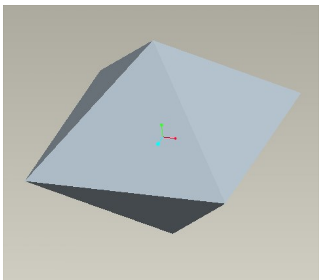


Fig.2 Octahedron in 3D software

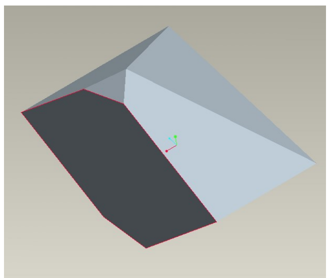


Fig.3 The results of a random cutting

In this process, it is necessary to make the average depth μz^* determined by the depth-of-cut function $f(z^*)$ be a part along the n_s (plane normal vector). And it changes in the maximum and the minimum size range of selected grinding wheel, as shown in Fig.4. The result of cutting 6 times is shown in Fig.6. As we can see from the diagram, the model is very similar to the irregular shape of the real abrasive particles.

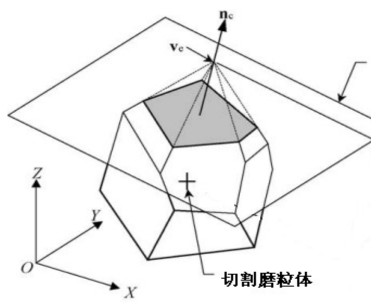


Fig.4 Random polyhedral particles of plane slices

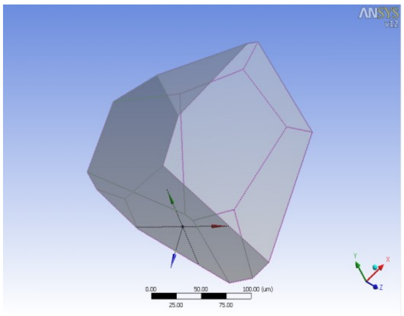


Fig. 5 Irregular abrasive particle after cutting 6 times

4. Simulation experiment of CBN abrasive particles wear

4.1 The simulation that carried by coupling smooth particle hydrodynamics (SPH) with finite element method

As a kind of brittle material, ceramic CBN shows brittle fracture and fracture in the process of wear, and its wear is minimal at the micro scale. Therefore, this paper adopted the method of smoothed particle hydrodynamics (SPH) to simulate the process of abrasive particles wear. Using the ANSYS/LS-DYNA post-processing software LS-Prepost to transform the built abrasive model into a SPH proton model, as shown in Fig.6.

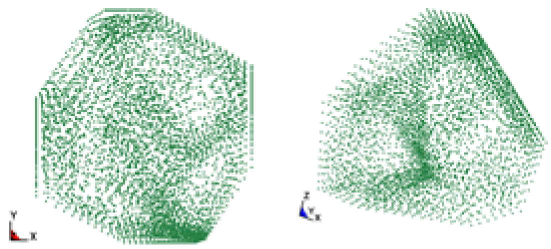


Fig. 6 SPH model of wear abrasive particles

The material separates from the workpiece which is a common type of material removal. Therefore, the Lagrange mesh in the finite element method can be used, so that the separation of grinding can be realized and the efficiency can be improved.

4.2 Design of simulation working condition

In order to study the wear of ceramic CBN grinding wheel under different grinding conditions, we designed the grinding wheel respectively in the condition of different grinding depths (10μm 25μm 40μm 55μm) while different grinding materials with different grinding speed are adopted, as shown in table 1.

Table 1 Grinding simulation process parameters

material	velocity (m/s)

45 40CrNiMoA Sic	80、120、150、200

4.3 Material model and unit selection

(1) Material model. CBN grinding wheel abrasive is a kind of brittle and hard material. It has the same material cutting model and failure form as Sic, ceramic, glass and so on. Therefore, it is possible to use the same material model as the above materials, namely LS-DYNA Johnson-Holmquist Ceramic. Specific material parameters are shown in table 2.

Table 2 Material parameters

Mterial Name	Density (g/cm3)	Modulus of Elasticity (Gpa)	Poisson Ratio	Material Model
CBN	3.45	706	0.15	Johnson-Holmquist Ceramic [9]
45	7.7	77	0.35	Johnson Cook [10]
40CrNiMoA	7.83	159	0.35	Johnson Cook [11]
Sic	3.215	183	0.17	Johnson-Holmquist Ceramic [9]

(2) Geometric model. In this paper, the simulated ceramic CBN grinding wheel has a particle size of 100/120 and a concentration of 150%. The size of workpiece is 500 *300 *150 (μm). As shown in Fig.7.

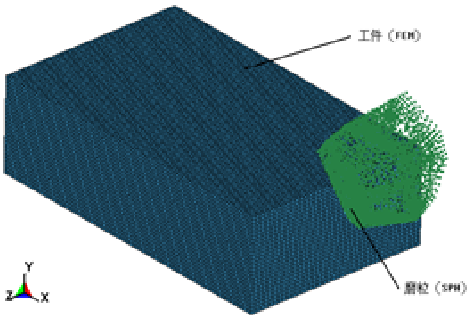


Fig. 7 Simulation model of single abrasive particle wear

(3) Unit selection. Since the simulation objects are all physical Solid, the Solid164 entity unit is selected in the LS-DYNA.

5. Simulation result analysis

The designed condition was imported into the finite element software LS-DYNA, grinding depth, grinding speed and grinding material constitute 48(4*4*3) orthogonal experiments, The CBN ceramic abrasive wear conditions in different situations were obtained. The abrasive wear is shown in Fig.8, It can be seen from the diagram that a few abrasive particles of SPH fall off and form worn particles.

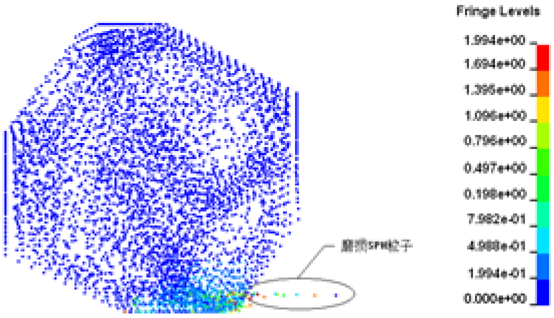


Fig. 8 Worn single abrasive particle

5.1 Effect of grinding speed on abrasive particle wear of grinding wheel

As can be seen from the Fig.9, the overall trend of the amount of abrasive particles wear shown in the four drawings is consistent. In the case of constant grinding depth, with the increase of grinding speed, the wear of abrasive particles will decrease. This is due to that the grinding speed increases while the unit grinding force decreases, then abrasive grinding force will be reduced and the effect on the abrasive particles decreases. Therefore, the wear loss of abrasive particles decreased. But it also can be seen that when a_p is 55μm, the abrasive particle wear changes more slowly, because it has been close to maximum grinding depth of the abrasive particle when the grinding depth is too large, grinding wheel abrasives are almost in destructive condition which make the abrasive particles unable to work again, so there is a little variation.

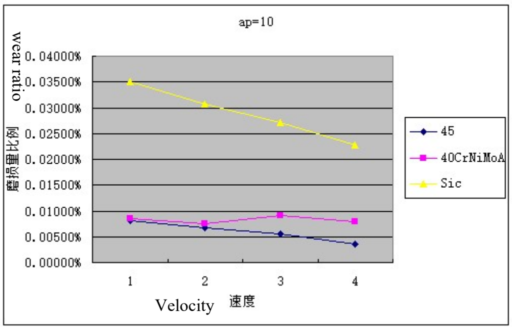
5.2 Effect of grinding depth on abrasive particle wear of grinding wheel

Fig.9 shows the abrasive particle wear simulation results of different materials at different grinding speeds with 4 different grinding depths. From the Fig.9, it can be seen that the abrasive particle wear increases as the grinding depth increases at a certain speed. Formula 1 [12] is the theoretical formula for the total wear loss after grinding m steps. From the formula, it can be known that the amount of wear increases as the grinding depth increases when other factors are determined.

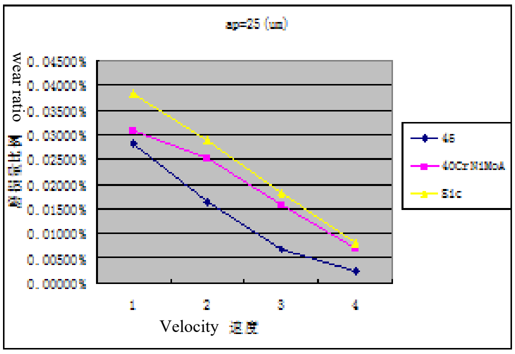
$$\begin{cases} a_{m,t} = a_p e^{-(K_1+K_2/\cos\alpha)t}[(K1+K2/\cos\alpha)t]^{m-1}/(i-1)! \\ \Delta r_m = a_p - a_p e^{-(K_1+\frac{K_2}{\cos\alpha})t}\sum_{i=0}^{i=m}\frac{[(K_1+K_2/\cos\alpha)t]^{i-1}}{(i-1)!} \end{cases} \tag{1}$$

Where:

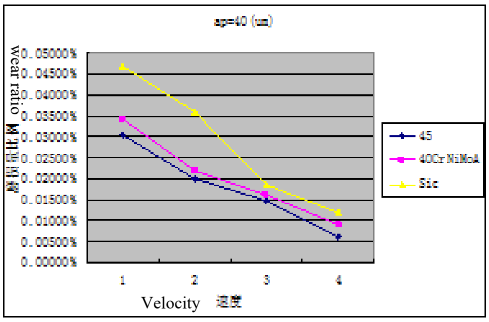
$$K_1 = C_1(\pi-2), K_2 = 2C_1, C_1 = Cd_w/\pi d_s \tag{2}$$



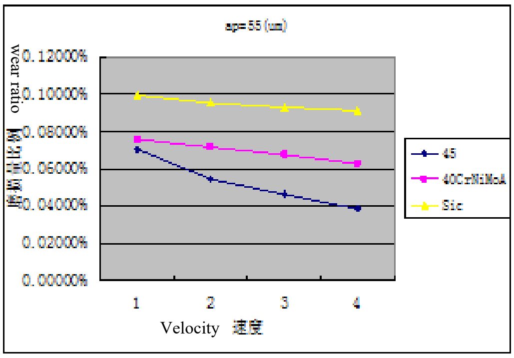
(a) The amount of abrasive loss when ap is10μm under different velocity and materials



(b) The amount of abrasive loss when ap is 25μm under different velocity and materials



(c) The amount of abrasive loss when ap is 40μm under different velocity and materials



(d) The amount of abrasive loss when ap is 55μm under different velocity and materials

Fig.9 Wear ratio of different materials at different grinding speeds under 4 different grinding depths

5.3 Effect of material properties on abrasive particle wear of wheel

In the simulation experiment, three kinds (45 #, 40CrNiMoA and SiC) of materials are used. From the Fig.9, we can see that with the same grinding depth and grinding speed, as the brittleness (i.e. SiC > 40CrNiMoA > 45 #) of the material increases, the wear of abrasive particles increases. That is because the greater the hardness of the material, the greater the elastic modulus of the material and unit grinding force of abrasive particle. Therefore, the greater grinding force, the greater abrasive particle wear.

6. Comparison of simulation results

Many experiments have been carried out on the wear test of ultra-high-speed ceramic CBN grinding wheel around the world. In China, a lot of universities and research institutes, such as Northeastern University, Hunan University, Tianjin University, Zhengzhou Research Institute for Abrasives & Grinding, have done a great deal of experimental researches and statistics. The

Fig.10 is the experiment of the grinding wheel radial wear of CBN grinding wheel with grinding depth of 5 mm, which is made by Qiu Jian [12] in several times. It can be seen from the experimental data chart that when 20 times in cycle and speed is 100 m/s, the wear is about 37 μm, the average amount of wear per time is about 1.85μm; when the speed is 75 m/s, the wear is about 43 μm, the average wear is about 2.15 μm each time. From Fig.8, we can see that when the speed is 80 m/s, the largest amount of wear was 1.99 μm, the data is basically identical.

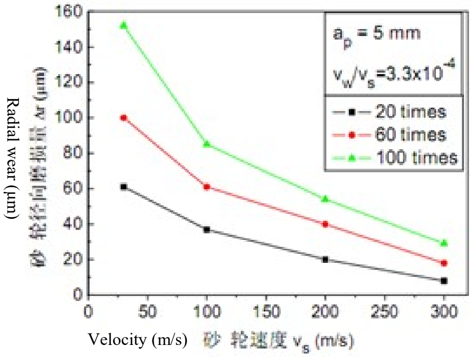


Fig. 10 Relationship between grinding wheel speed and radial wear of grinding wheel [13]

Fig.11 shows the experiment of the grinding of ceramic CBN grinding wheels on the side of the grinding wheel, which was made by Xiu Shichao [13]. We can see from the chart, the grinding depth is 0.010mm and grinding with emulsion, the wear volume of wheel side is about 2μm. In this paper, the simulation experiment ignores the effect of the friction coefficient in the simulation process, so the maximum wear of 1.99μm is also basically identical.

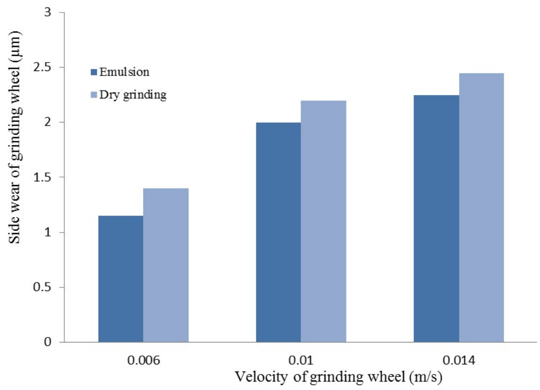


Fig. 11 Results of CBN grinding wheel wear test [13]

6. Summary

(1) The wear mechanism of ceramic CBN grinding wheel and the whole grinding wheel were studied. And the study which established a single abrasive particle irregular simulation model making it more suitable for real grinding situation.

(2) Orthogonal simulation experiments of three different kinds of materials, four different grinding depths and four different grinding speeds were carried out to obtain a single piece of abrasive wear ratio data, and compared with the existing physical experimental data, the overall trend is basically the same, it proved that the simulation experiment was basically successful.

(3) According to the simulation results, the grinding depth is controlled between 10μm~50μm, and the grinding speed is about 120 m/s ~ 230 m/s in the actual grinding process, it can be bigger for some relatively large plastic materials.

(4) As the experiments are based on ANSYS / LS-DYNA software simulation, it will set different simulation parameters according to different conditions, it can't be completely consistent in the case of simulation experiments, so there will be some error inevitably.

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