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Study on Characteristics of Two Phase Flow Field in Grinding Zone of Large Spiral Angle Groove Wheel

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Abstract: Aiming at the high specific removal energy and heat generation rate in grinding process, and the low heat transfer efficiency in grinding arc zone of ordinary grinding wheel, the problems of local high temperature and grinding burn are easy to occur. In this paper, the plane grinding of grooving wheel with large spiral Angle is taken as the research object, and the numerical analysis model of gas-liquid two-phase flow field in wedge zone and grinding arc zone is established. The enhancement mechanism of heat transfer performance in grinding arc of large spiral Angle groove wheel was investigated. The results show that the flow of grinding fluid into the grinding arc will be hindered by the airflow around the grinding wheel, resulting in backflow and side leakage. Compared with ordinary grinding wheels without grooves, the backflow and side drainage in grinding zone of big spiral Angle grooves grinding wheels are significantly reduced, and a large amount of grinding fluid is transported in the heat exchange channel. The spiral groove has a good conduction effect on the grinding fluid, and the grinding fluid is easier to enter the grinding zone, thus significantly improving the heat transfer performance of the grinding zone and effectively reducing the grinding temperature during the grinding process.

Keywords: Large spiral Angle groove grinding wheel, Grinding zone, Two phase flow field, heat transfer performance.

1. Introduction

The grinding process will generate a lot of heat in the grinding arc zone [1-2]. If the grinding temperature cannot be effectively reduced in time, the grinding surface quality will be reduced [3-4], and the workpiece surface will be burned seriously. Pouring grinding is an important way to take away the heat of grinding arc [5-6].

In the grinding process, a complex gas-liquid two-phase flow field is formed in the grinding arc area between the grinding fluid ejected from the nozzle and the air flow field around the grinding wheel. At the same time, the big spiral Angle groove grinding wheel has contact zone and heat transfer zone, and the flow state of grinding fluid in the two zones is very different. The flow field affects the cooling and lubrication of grinding arc, and further affects the surface quality of workpiece to be machined. Therefore, it is significant to study the characteristics of gas-liquid two-phase flow field in grinding arc. Professor Li Changhe's team established the effective grinding fluid flow field model of coarse-grained grinding wheels, and established the gas barrier layer flow field model [7] and fluid volume multiphase flow grinding fluid flow field model with porosity as the key parameter [8]. The research results show that the grinding wheel speed, gas barrier layer flow field characteristics, grinding fluid jet velocity and the minimum clearance in the grinding arc zone have great influences on the effective flow rate in the grinding arc zone. Professor Ding Wenfeng's team established a three-dimensional finite element model for two-phase flow field in the wedge zone, and experimentally studied the cooling capacity of the flow field in the arc zone under different grinding speeds and grinding fluid speeds [9]. The results show that with the increase of nozzle distance, the velocity of grinding fluid decreases rapidly after the initial slight increase, and very little grinding fluid can enter the grinding arc zone. With the increase of grinding speed, a higher grinding fluid speed is needed to break the cooling barrier of the gas layer. The critical grinding fluid speed breaking the gas barrier into the grinding arc zone is obtained through theoretical calculation and experiment. Jiang Xiangyan carried out finite element simulation for the effective utilization of grinding fluid [10]. The results show that the gas barrier layer flow field has a certain effect on the supply of grinding fluid, and different grinding process parameters have a great effect on the effective flow rate. The grinding fluid produces obvious reflux phenomenon at the minimum clearance, which is not conducive to cooling and heat dissipation. At the same time, the optimization strategy of how to improve the effective utilization rate of grinding fluid is proposed. First, the distribution law of the flow field of the gas barrier layer is rationally utilized. The second is to optimize the position of grinding fluid nozzle and jet Angle. Xiao Linfeng carried out simulation of flow field in grinding zone and experimental research on grinding performance of orderly micro-groove structured wheel [11]. The research results show that the micro-groove structure can transport more grinding fluid into the grinding arc, and the cooling fluid is quickly taken out by the micro-groove structure, which promotes the flow of grinding fluid inside the grinding arc, increases the effective flow rate in the grinding zone, further improves the lubrication and cooling performance in the grinding zone, and enhances the chip capacity of the grinding wheel. The effective flow rate of grinding fluid is increased and the service life of grinding wheel is prolonged.

In this paper, the VOF multiphase flow model in FLUENT software was used to simulate and analyze the gas-liquid two-phase flow field in grinding arc area of the big spiral Angle groove wheel, and the influence of spiral groove on grinding liquid flow state in grinding arc area was studied.

2. Establishment of Simulation Model of Two Phase Flow Field In Grinding Arc

2.1. Mathematical model

In computational fluid dynamics (CFD), there are mainly three kinds of models used for multiphase flow simulation [12-13], namely, VOF model, Mixture model and Eulerian model. Suitable simulation models should be adopted for different multiphase flow situations. In the analysis of gas-liquid two-phase flow field in grinding arc area, air and grinding fluid are not mutually soluble, so the VOF model is adopted in this paper. To this end, the following mathematical model is established.

Continuity equation:

$$\frac{\partial \rho}{\partial t}+\frac{\partial u_i}{\partial x_i}=0 \quad (1)$$

Volume fraction equation:

$$\alpha_{\mathrm{m}}+\alpha_{\mathrm{n}}=1 \quad (2)$$

Both the multiple reference frame method and the sliding grid method are the best choices to deal with the rotation area of the wheel with big spiral Angle groove. Considering solving the rotation problem of gas-liquid two-phase flow field in grinding arc, the purpose is to observe the flow law of grinding fluid in grinding arc, and explore the interaction between grinding fluid and air flow field in grinding arc. The multi-reference frame method adopts steady-state calculation and cannot show the flow process of grinding fluid. Therefore, it is more suitable for simulation of gas-liquid two-phase flow field in grinding arc of large spiral Angle grooved grinding wheel to adopt sliding grid method and VOF two-phase flow model. For ordinary grinding wheel and annular grooved grinding wheel, direct wall rotation method and VOF model can be adopted. Both methods adopt transient calculation.

The sliding grid is the rotation of the segmented moving region in the fluid domain, which involves the movement of the grid [14-15]. Therefore, the grid nodes of the interface of the dynamic and dynamic regions cannot be overlapped by the shared topology. Therefore, it is necessary to encrypt the interface of dynamic and static regions in order to improve the calculation accuracy and reduce the analysis error. The governing equation of the sliding grid method is,

$$\frac{\partial \rho}{\partial t}+\nabla\cdot\rho\vec{v}_r=0 \quad (3)$$

The gas-liquid two-phase flow field in grinding arc is a complex flow process with strong rotation characteristics, so RNG *k-ε* turbulence model is still used to calculate the flow field.

2.2. Geometric model

In this paper, 3D geometric modeling method was adopted to simulate the grinding process of the big spiral Angle groove wheel under the condition of wet grinding, and the influence law of the structure parameters and grinding process parameters of the big spiral Angle groove wheel on the grinding fluid flow state in the grinding arc region was compared and analyzed.

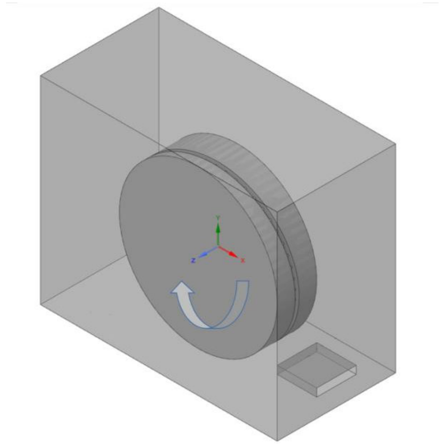

Figure 1. 3D geometric model of two phase flow field

Figure. 1 shows the three-dimensional geometric model of gas-liquid two-phase flow field in the grinding arc of a groove wheel with a large spiral Angle. During the grinding process, the grinding liquid ejected from the nozzle enters the grinding arc area with the rotation of the grinding wheel for cooling lubrication and grinding chip cleaning, so the grinding liquid nozzle is placed at the entrance of the wedge area. The width of the grinding liquid nozzle is equal to the width of the grinding wheel. This setting is mainly to avoid the underestimation of the conduction effect of the spiral groove on the grinding liquid due to insufficient liquid supply.

2.3. Simulation parameter setting

The horizontal distance between the inlet of the grinding fluid nozzle and the minimum clearance was set as 60 mm, and the height of the nozzle from the workpiece surface was 10 mm, 20 mm and 30 mm, respectively. Among them, the nozzle height refers to the distance between the bottom surface of the nozzle and the workpiece surface. For the convenience of description, the nozzle heights of 10 mm, 20 mm and 30 mm were defined as the lower jet, the middle jet and the upper jet.

In order to simplify the simulation calculation of gas-liquid two-phase flow field in grinding arc zone, the following simulation conditions are defined:

(1) Using transient simulation and double precision solver calculation;

(2) Water-based grinding fluid is used, which is replaced by water in FLUENT;

(3) In the study of gas-liquid two-phase flow field, the influence of gravity on grinding fluid cannot be ignored. The gravity direction is the negative direction of Y-axis, and the magnitude is 9.81m /s2.

(4) The RNG *k-ε* turbulence model with cyclone dressing was used to calculate the gas-liquid two-phase flow field, and the enhanced wall function was used to deal with the grinding fluid flow near the wall.

(5) The grinding liquid nozzle is the Velocity Inlet.

3. Simulation Results and Analysis of Two-phase Flow Field in Grinding Arc

The key structural parameters of large spiral Angle grooved grinding wheel include spiral Angle, groove width and groove depth, and the influences of the three on grinding fluid flow state are independent of each other. Therefore, single factor analysis was used to keep the groove width of 3 mm, groove depth of 4 mm and grinding process parameters and other simulation conditions consistent. Firstly, the influence of spiral Angle on grinding fluid flow state was studied. The circular velocity of fixed grinding wheel was 30 m/s, the velocity of grinding fluid was 1 m/s, and the middle jet was used. The volume fraction distribution rendering diagram of grinding fluid in gas-liquid two-phase flow field in grinding arc area of large spiral Angle groove wheel with different spiral angles is obtained, as shown in Figure 2 to Figure 5.

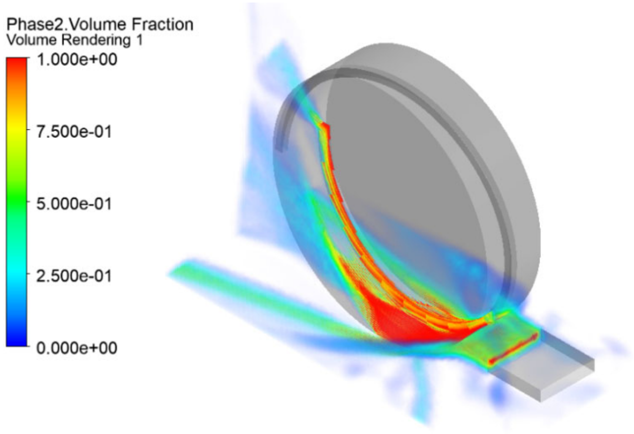

Figure 2. Helix Angle 86.36°

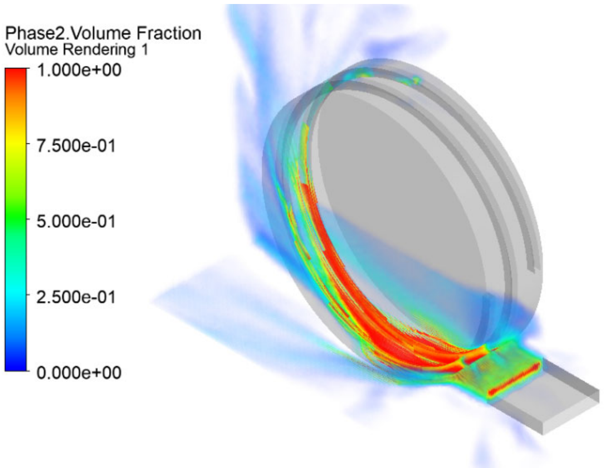

Figure 3. Helix Angle 88.18°

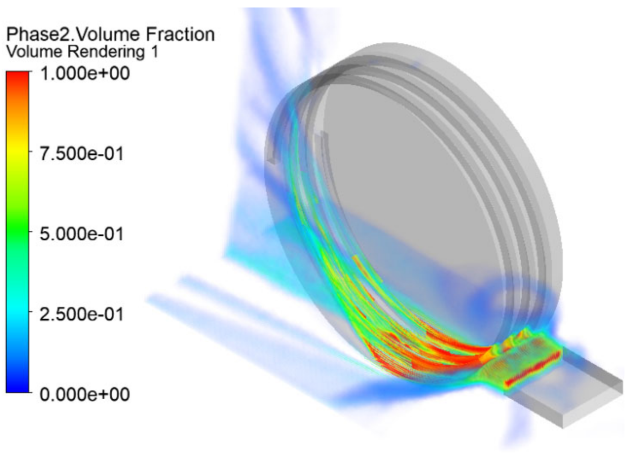

Figure 4. Helix Angle 88.78°

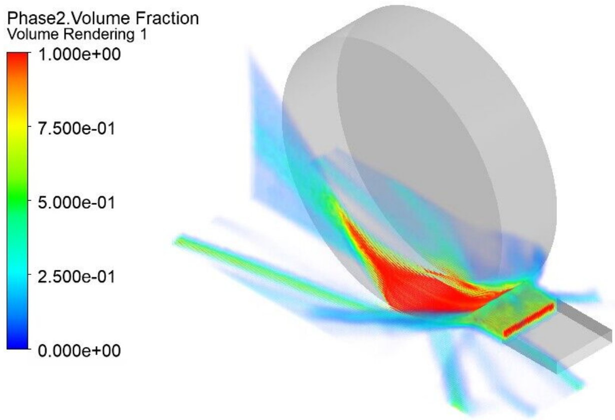

Figure 5. Ordinary grinding wheel without grooves

As can be seen from the figure above, the grinding fluid is ejected from the nozzle at a certain speed and mixed with the air in the environment during the process of breaking through the airflow barrier. There are three places to go. One is to enter the grinding arc area to complete the cooling and lubrication of the workpiece. Second, it is thrown to both sides of the grinding wheel due to the side leakage effect of the airflow in the grinding zone; Third, the backflow of grinding fluid is not broken through the airflow barrier. The lateral discharge and backflow of grinding fluid will reduce the effective utilization rate of grinding fluid, so the flow rate of grinding fluid entering the grinding arc should be increased.

The grinding fluid exists in the gap between the grinding wheel and the workpiece, including the minimum gap and the heat transfer channel, is the effective flow rate; It also exists on both sides of the grinding wheel. This part of grinding fluid fails to enter the grinding arc area for cooling, which is an invalid flow rate. With the increase of spiral Angle, the contact area between grinding wheel and workpiece decreases, the heat dissipation area of grinding surface increases, the effective flow into the heat exchange channel into the grinding arc area increases, the ineffective flow decreases, and the grinding fluid is more evenly distributed in the width direction of grinding wheel. In addition, the position of the spiral groove changes continuously with the rotation of the grinding wheel, that is, the heat transfer channel moves horizontally along the width of the grinding wheel, which will realize the complete cooling of the grinding fluid on the grinding surface. In contrast, the effective flow rate in grinding arc area of ordinary grinding wheel is much less. Firstly, there is no heat transfer channel to support the transportation of grinding fluid; secondly, a large amount of grinding fluid fails to enter the grinding arc area due to the influence of high pressure gas field, and is thrown out of both sides of the grinding wheel, resulting in a large amount of waste of grinding fluid. Therefore, the big spiral Angle groove grinding wheel has obvious advantage of heat transfer.

4. Conclusion

In this paper, the VOF method is used to simulate the gas-liquid two-phase flow field in the wedge zone and grinding arc zone of the big spiral Angle groove grinding wheel. The results show that：

(1) The flow of grinding fluid into the grinding arc will be hindered by the airflow around the grinding wheel, resulting in reflux and side leakage phenomenon. Compared with the ordinary grinding wheel without grooves, the backflow and

side drainage phenomenon of the grinding zone of the big spiral Angle grooves grinding wheel are significantly reduced, and a large amount of grinding fluid is transported in the heat exchange channel.

(2) The structural parameters of the grinding wheel have a great influence on the flow state of grinding fluid in the grinding arc. With the increase of spiral Angle, groove width and depth, the grinding liquid integral in heat exchange channel increases gradually. The structure breaks the original stable flow state of grinding fluid and greatly increases the velocity of grinding fluid in the heat transfer channel.

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