Simulation of Gap Flow Field in EDM for Polygon Hollow Electrode

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***Abstract*-Aiming at the gap flow field of particle-reinforced aluminum matrix composites in EDM machining with round and polygonal hollow electrode, a model simulation was conducted to study the effect of hollow polygonal electrodes on the process of EDM drilling hole and to reveal the distribution law of the discharged debris concentration betwteen the gap flow field of a polygonal electrode.The simulation results show that the distribution of the flow field in the machining gap was almost the same for the round hollow electrode, the quadrilateral hollow electrode, the pentagon hollow electrode and the hexagon hollow electrode. The flow velocity of the polygon hollow electrode was smaller than that of the round hollow electrode. The distribution of discharged debris concentration indicated that the hexagon hollow electrode has the best concentration distribution of the discharged debris.**

***Index terms*-Polygon hollow electrode; MMCs; EDM; Flow field; Computer simulation**

I. INTRODUCTION

In the past, there were a lots of studies on the gap flow field simulation of EDM machining hole [1-3], but there were not many simulations for special-shaped electrodes. In order to verify whether the gap flow field of polygon electrode for EDM machining hole had more advantages, in this paper,a simulation had been conducted to study.

In the process of EDM drilling hole, the distribution of discharged debris bewteen the gap depends on the flow of the working fluid in the machining gap, and the distribution of the discharge debris bewteen the gap also reflects the discharge of debris from the process of EDM machining, and this also greatly affect the discharge frequency and discharge position in EDM.Besides,a certain concentration of discharged debris will affect the discharge channel conductivity and deionization, if the deionization is not so good that it will cause secondary discharge phenomenon, which would results in the unstable process.Hence,It has a greater impact on the processing efficiency and the surface quality. The structure of the polygon hollow electrode is different from the round hollow electrode, and the distances between the gaps were also different during the processing,which results in the concentration of the debris of discharge bewteen the gap in the polygon hollow electrode was different from that of the round hollow electrode.It is great significance to study the polygon electrode,especially for the aluminum matrix composite materials,which has a high requirement on the debris of discharge.It is one of the important way to improve the machining efficiency for EDM machining metal matrix composites, ensure the processing stability, and improve the precision of drilling small hole.

Electrode rotation and the hollow inner hole flush electrode are important factors affecting the machining gap flow field, which improved the stability of drilling hole, processing efficiency and machining accuracy [3]. Previously, it was experimentally verified that the machining efficiency and the effect under the condition of the rotary electrode were significantly better than that of the stationary electrode [4-6]. Rotating electrode will affect the flow of fluid bewteen the gap flow field, and then affect the deposition and distribution of the discharged debris. Therefore, under the condition of the rotary spindle, it is critical to study the gap flow field for the EDM drilling hole.In the process of the EDM drilling hole, the use of a hollow inner hole flush was more advantageous than the conventional processing which immersed the workpiece and the motor in the working fluid,because the working fluid of the hollow inner hole is supplied by the hydraulic pump and it has a certain pressure, which facilitate the fluid flow in the working fluid, and it will be easier to discharge the debris bewteen the gap. Therefore, different working fluid pressures would have different effects on the flow velocity of the fluid in the gap flow field.

The structure of the polygon hollow electrode was different from the structure of the round hollow electrode. The wall surface of the polygon hollow electrode had corners, and the outer wall surface of polygon hollow electrode was planar, unlike the round hollow electrode, the outer wall surface is a round surface. The advantage the outer wall surface of the plane was that, when the electrode rotated, The wall surface would stir the debris in the gap, hence, making the discharge debris get greater momentum and speed. Compared to the round wall urface,it will produce stirring force, which would promotes the accelerated diffusion of discharge debris, and that the rotating outer planar wall would press the gap fluid, causing the debris of discharge to be ejected toward the outlet with the fluid.

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In this paper, a model simulation was conducted to study the gap flow field of particle-reinforced aluminum matrix composites in EDM machining with polygonal hollow electrode. By comparing the model of the gap flow field between polygon hollow electrode and round hollow electrode, the distribution law of the discharged debris concentration betwteen the gap flow field of a polygonal electrode was analyzed, and the influence of polygon hollow electrode on the EDM machining hole was studied.

II. THE ESTABLISHMENT OF A SIMULATION MODEL

A. *EDM Machining Gap*

The machining gap is a problem that needs to be researched in the flow field simulation the EDM, and it had a great influence on the discharge of the debris. The machining gap is the discharge gap between the tool electrode and the workpiece. Usually, the machining gap changes with the machining process. If the machining gap can be kept within a small variation range, a higher machining accuracy could be obtained. Therefore, in addition to the factors of pulse power supply and servo feed, the machining gap control is also related to the working fluid, tool electrodes, and workpiece materials and so on. It can be expressed by the following empirical formula:

$$S=K_u\times u+K_R\times W_m+S_m \tag{1}$$

Where, S is the discharge gap; u is the open circuit voltage; Ku is the coefficient related to the working fluid and the concentration of electrolytic; KR is a constant, related to the processed material; Wm is the single pulse energy; Sm is a mechanical gap considering thermal expansion, contraction, vibration, and other effects.

In this paper,the experiment was performed on DD703 high-speed EDM small hole processing machine. It used a copper electrode with an outer diameter of 2.5mm and an inner diameter of 1mm. The processing current was changed from 4A to 12A, the pulse width was changed from 16us to 56us, and the pulse interval was changed from 8us to 56us. The liquid is deionized water, because the machining gap would be increased with the increaing of size and the current of the copper electrode, so the simulation used a discharge gap of 150um to simulate.

Mathematical Model

For the purpose of studying the gap flow field of a polygon hollow electrode,the law of conservation of mass and the law of conservation of momentum are taken into consideration. The mass conservation equation is as follows:

$$\frac{\partial\rho}{\partial t}+\Delta\cdot(\rho V)=S_M \tag{2}$$

Where, ρ is the fluid density;t is the time;V is Speed vector;SMis the mass of the discharged debris bewteen the gap.

The law of conservation of momentum was as follows:

$$\frac{\partial\,(\rho V)}{\partial t}+\nabla\cdot(\rho VV)=-\nabla p+\nabla\cdot(\tau)+\rho g+F$$

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Where, ρ is the fluid density;g express the force of gravity acting on a microelement;F is other external body force; τ is viscous stress tensor.

In the simulation of a polygonal hollow electrode, the liquid phase in the gap flow field is an Incompressible fluid so that it is set as a continuous phase.In the equilibrium state of processing,the flow of solid particles and working fluid is a stable flow and the interface between the solid particles and the working fluid is a geometric surface without weight, momentum and energy.

Physical Model

The machining schematic diagram of a polygonal hollow electrode is showed in Figure 1.A three-dimensional model of a circular hollow electrode and a polygonal hollow electrode is showed in Figure 2.The diameter of the circular hollow electrode is 2.5mm, the diameter of the circumscribed circle of the polygonal hollow electrode is 2.5mm, and the diameter of the flush hole of the copper electrode is 1mm.Theoretically the holes machined by the polygonal hollow electrode and the circular hollow electrode share the same size.

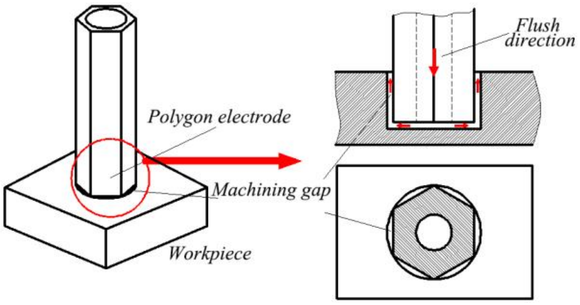


Figure 1. Machining schematic diagram of a polygonal hollow electrode

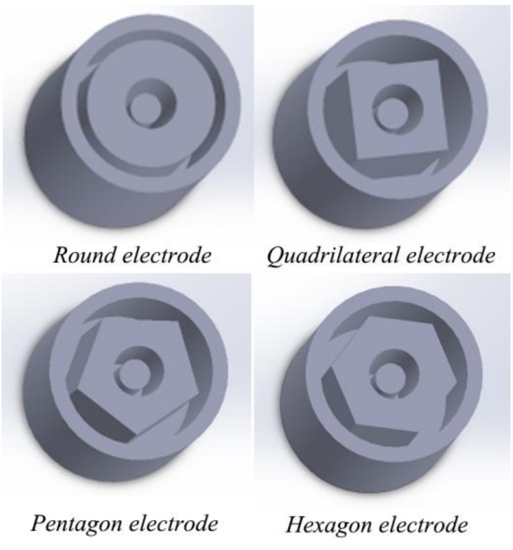

Round electrode
Quadrilateral electrode
Pentagon electrode
Hexagon electrode

Figure 2. Different 3D eletrode models of drilling hole

III. FLOW FIELD GAP SIMULATION

FLUENT,a software that simulates complex flow in an incompressible to highly compressible range,is employed to simulate the flow field gap model.FLUENT uses a variety of solving methods and multi-grid acceleration convergence techniques so that it can achieve the best convergence speed and solution accuracy.

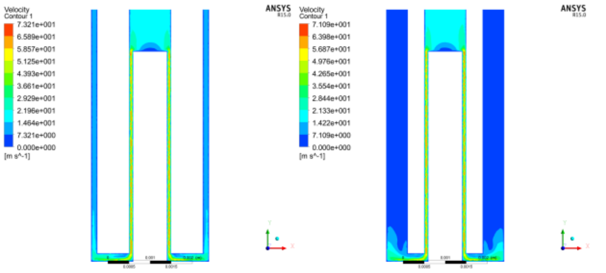
A Initial Conditions and Boundary Conditions

It’s a transient simulation of gap flow that requires a given boundary condition.The continuous phase boundary condition is that the working fluid enters the rotating electrode hole at a pressure of 4 MPa through the pressure pump and this inlet boundary condition is set to an inlet pressure of 4 MPa.The continuous phase flows uniformly from the copper electrode's flush hole.Working fluid passes through the hole in the electrode, entering the bottom processing area and then passes through the gap between the electrode and the workpiece.Finally it flows into the air.This boundary condition is that the outlet pressure is set as the standard atmospheric pressure, 1.013X105Pa.When processed the surface of hole wall it use no-slip boundary condition "Wall".The factor gravity is taken into consideration in gap flow field and the rotation speed of the electrode is 800r/min.The boundary condition in contact with the surface of the electrode is set to the “Wall”, rotating at a speed of 800 r/min about the Y axis.

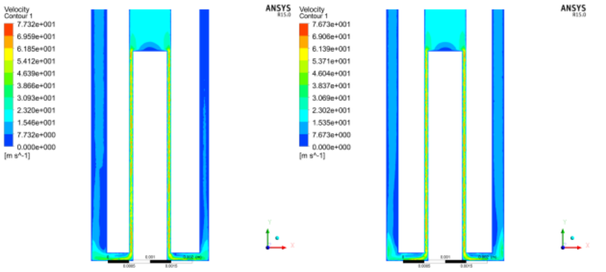
The drilling depth is 5mm.When the hole is punched, the particles are evenly thrown,whose throwing surface is defined as the bottom of the electrode,all processing surfaces of the workpiece and a little side surface adjacent to the processing surface. The eroded particles thrown by the ejection surface are uniformly distributed on the ejection surface.The initial speed of all particles is (0,0,0).The Cu particle whose mass flow is 2.67X10-6kg/s and particle diameter is 10um ,is flew at the bottom of the electrode. The workpiece processing surface throws Al and Al2O3 particles, in which the mass flow of Al particles is 2.089×10-6 kg/s, the particle diameter of Al is 10 mm and the mass flow of Al2O3 particles is 0.522×10-6 kg/s and the particle diameter of Al2O3 is 10 mm.The size of the erosion particles is related to the working fluid medium, processing power and tool workpiece material.Through the Scanning Electron Microscope observation and analysis, most of the debris size is about 10um.

B Simulation Results and Analysis

In general, the lower the working fluid flow rate is, the higher the concentration of erosion products would be, and the smaller the flow field gap is, the easier the debris would be blocked, therefore,it is diffcult to processing. It can be predicted that the EDM debris removal situation by studying the working fluid flow field. After simulation, the gap flow field velocity distribution of the electrode is shown in Figure 3.



(a) Gap flow field of round electrode (b) Gap flow field of quadrilateral electrode



(c) Gap flow field of pentagon electrode (d) Gap flow field of hexagon electrode

Figure 3. Machining gap flow field diagram of different electrodes

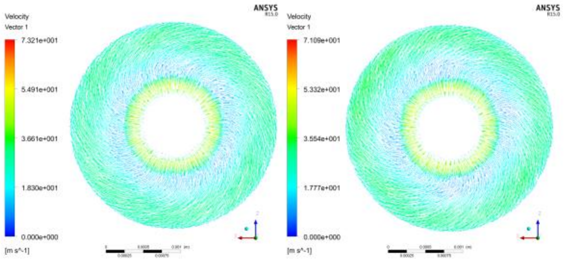
The fluent software was used to simulate the gap flow field of four different electrodes, where,in the highest speed of the round hollow electrode machining gap was 55m/s, the minimum speed was 20m/s, and the maximum speed of the quadrilateral electrode machining gap was 54m/s, the minimum speed is 14m /s, the maximum speed of the pentagon electrode machining gap was 57m/s, the minimum speed was 15m/s, the maximum speed of the hexagon hollow electrode machining gap was 56m/s, the minimum speed was 16m/s.According to the distribution of the fluid field bewteen the machining gap,the distribution of fluid field of polygon hollow electrode and round hollow electrode are similar, but in the process of fluid flow from the bottom to the machined gap, because the gap size of polygonal hollow electrode was larger than the round hollow electrode,Therefore, the speed had a larger gradient at this situation, and the pressure also decreased rapidly.

It was so important for the gap flow field of EDM machining to discharge debris, it directly determines the processing efficiency and processing surface quality, for example, the flow field of the bottom 0.2mm thick cylindrical processing area, in its axial direction,the flow velocity near the workpiece was much greater than that of the tool electrode, which is due to the effects of fluid gravity and momentum changes,and it also helps to increase the material removal rate and reduce the tool wear rate; in its radial direction, the flow velocity near the inner hole was the largest and gradually decreases toward the outer wall.

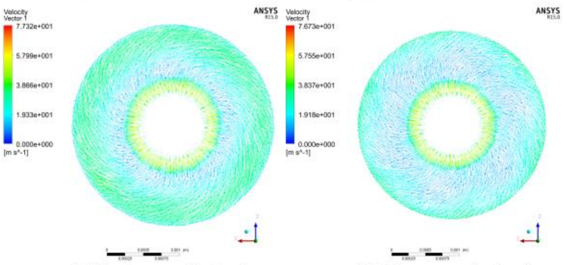
From the distribution diagram of gap flow line at the bottom, which was shown in Fig 4,the streamline was a spiral curve, it was due to the influence of the spindle speed,it also shows that the discharge of the debris was not only affected by the flushing pressure, but also by the spindle rotation.Because the spindle rotation created additional centrifugal force on the working fluid and promoted the spread of electro-eroded debris.In the process of EDM discharge, a discharge channel was created between the two gap, which caused gasification of the material to form a bubble explosion, thus causing disturbance of the working fluid in the processing area, so that the electro-eroded at the same radius was not evenly distributed,however,because of the rotating electrode,the additional centrifugal force could be added to allow the electro-eroded debris to be thrown outwards,which would also facilitate the uniform diffusion of the discharged debris to the outside.

As could be seen from Figure 3, the velocity of the fluid attenuates as it flows from the machining gap to the side gap,in which the flow velocity of the quadrilateral electrode reduced the most obviously, followed by the pentagon electrode, then the hexagon electrode, and finally the round hollow electrode. The greater the speed decay, according to Bernoulli's equation, the pressure difference was also large where the flow velocity changed greatly, and the larger the pressure difference at the bottom corner, the easier the electro-eroded debris in the processing area was rapidly passed through the bottom processing gap to the outside gap.Therefore, from the point of view of the processing gap clearance patency,the processing gap patency of quadrilateral electrode was the best,and the round electrde had the worst of it.However, in addition to considering the flow velocity problem, the actual machining efficiency was also related to the cross-sectional area and shape of the electrode.The larger the machining contact area and the line speed at the bottom of the electrode, the larger the discharge debris amount per unit time.

The difference between the flow fields of the four different electrode gaps was the outer gap. The flow velocity in the outer gap of the round hollow electrode was the largest, followed by the hexagon electrode, and then the pentagon electrode,and the quadrilateral electrode had the smallest gap flow velocity.

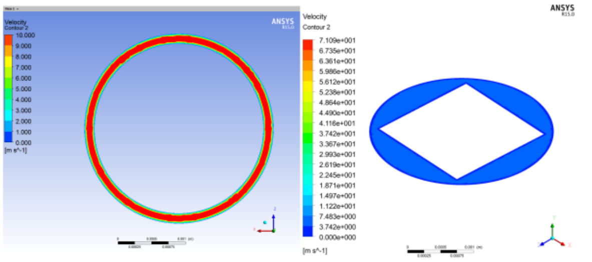


(a) Round electrode *(b) Quadrilateral electrode*

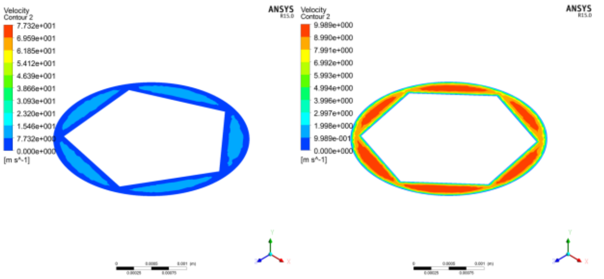


(c) Pentagon electrode *(d) Hexagon electrode*

Figure 4.The streamline distribution diagram of processing gap in the bottom



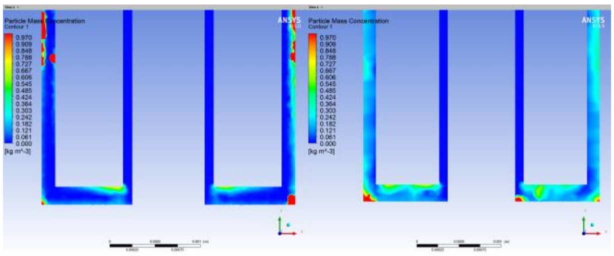
(a) Round hollow electrode *(b) Quadrilateral hollow electrode*



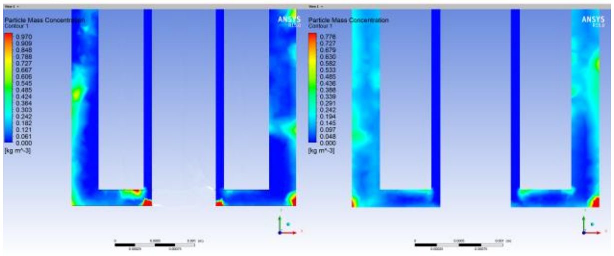
(c) Pentagon hollow electrode *(d) Hexagon hollow electrode*

Figure 5. Outlet velocity distribution of different hollow electrodes

The distribution of the flow velocity at the outlet of the polygonal hollow electrode was shown in Fig 5.The outlet velocity of the hexagon electrode could reach 10 m/s at the highest, the maximum flow velocity at the outlet of the quadrilateral electrode was 6 m/s, and the maximum flow velocity at the outlet of the pentagon electrode was approximately 8 m/s,the round hollow electrode outlet had an average flow velocity of 10 m/s. By calculating the cross-section,the outlet gap cross-sectional area of quadrilateral electrode was 3.03mm2, the outlet gap cross-sectional area of pentagon electrode was 2.64mm2, the outlet gap cross-sectional area of hexagon electrode was 2.10mm2,and the outlet gap cross-sectional area of round hollow electrode was 1.25mm2.



(a) Round hollow electrode *(b) Quadrilateral hollow electrode*



(c) Pentagon hollow electrode *(d) Hexagon hollow electrode*

Figure 6. Erosion particle concentration distribution

From the concentration distribution of the electro-eroded debris Fig 6, it could be seen that both the round hollow electrode and the polygonal hollow electrode had the highest concentration of discharged debris at the bottom corner of the processing gap.The debris of discharge was easily accumulated at the corners due to the gravity and the centrifugal force of spindle rotation.In addition, the direction of the flow velocity changed and it was difficult to wash away the debris.Due to the smaller flow field gap of round hollow electrode, the pressure was greater, and the flow velocity was faster, so the average concentration of the eletro-eroded debris in the gap area was small, but the smaller gap size makes it easier for debris to accumulate in the side gap,and it was easy to cause blockage and affect the subsequent debris removal.while the gap size of the polygonal electrodes was larger than those of the circular electrode, so the gap flow velocity would be lower, although the concentration of the discharge debris would be larger,the distribution of debris in the flow field was more dispersed, because the polygonal hollow electrode had an angular structure and planar side walls. When the electrode rotated, the fluid bewteen the gap was squeezed all the time, and the side wall of the electrode plane also stirred the electro-eroded debris in the fluid field,as a result,the discharge debris obtained greater momentum and speed, so that the debris was more likely to be spread,which would not be accumulated in the side gap, the squeezed fluid would also be gotten additional upward pressure,so It was more easily to discharge the debris from processing gap of the bottom.

IV. CONCLUSION

By means of using Fluent software, this paper simulates the gap flow field of machining aluminum matrix composites with EDM using polygonal hollow electrode.By comparing the flow field distribution and erosion distribution of particulates of circular hollow electrodes, quadrilateral hollow electrodes, pentagonal hollow electrodes and hexagonal hollow electrode,it can be concluded as as follow:

(1) As a result of the gap flow velocity simulation, the distribution of the flow fields in the machining gap is approximately the same for the circular hollow electrode, the quadrangular hollow electrode, the pentagonal hollow electrode, and the hexagonal hollow electrode.However, due to the large lateral gap of the polygonal hollow electrode, the flow velocity will be greatly reduced at the side and the pressure will also be greatly decreased, which is beneficial for the erosion of the particles flow from the processing gap into the side.The distribution of fluid in the lateral gap appears different and the flow velocity of the polygonal hollow electrode is smaller than that of the circular hollow electrode.

(2) The concentration distribution of the gap erosion particles indicates that the density of the circular hollow electrode in the processing gap is small, but the particles of erosion into the side gap is likely to cause blockage, while the polygonal hollow electrode has a greater concentration in the machining gap, but the angular structure of polygon hollow electrode is conducive to chip removal.Due to the angular surface of the polygonal hollow electrode and the planar structure of the outer wall, the momentum and velocity of the side erosion particles are increased after the collision and the side fluid is squeezed,which are helpful to exhaust the particles of erosion.The result of simulation shows that the hexagonal hollow electrode has the best concentration distribution of the etched particles.

(3) Through the analysis of simulation, preliminary comparison of the flow field of polygon hollow electrode and circular hollow electrode during processing is made, which will prepare some theoretical preparation for the later verification test.

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