Influence of the Agitation Pipe on the Flow Field of Electroplating Tank in the Electroplated Diamond Wire Saw

Derong Duan¹,²,³, Peiqi Ge²*, Zhigang Gong³, Fuli Huang³ and Guangzhou Cao³

¹School of Mechanical Engineering, University of Jinan, Jinan, Shandong, 250022, China
²School of Mechanical Engineering, Shandong University, Jinan, Shandong, 250061, China
³Shantian Abrasive co., LTD, Linyi, Shandong, 276702, China

*Corresponding author’s e-mail: me_duandr@ujn.edu.cn

Abstract: In order to solve the problem of diamonds sedimentation in electroplating tank and uneven distribution of diamonds in coatings, the fluid flow in the electroplating tank formed by three structure kinds of agitation pipe was compared and analysed. Results showed that the middle inlet type agitation pipe can significantly improve the fluid uniformity in the electroplating tank, and setting sand blasting ports at both ends of the agitation pipe can avoid the formation of fluid "dead zone". Along the direction of the agitation pipe, the middle inlet type agitation pipe improves the overall flow of the fluid. In the position of the wire saw passing through, the difference of the speed in the electroplating tank of the middle inlet is 47.17% and 15.25%, which is significantly lower than that of the water inlet structure of one end by 134.48%. As a result, it can significantly improve the plating effect of the wire saw.

1. Introduction

Electroplated diamond wire saw has the advantages of small wire diameter, high cutting efficiency, wear resistance. It plays an important role in the cutting field of brittle and hard materials such as monocrystalline silicon [1]. Continuous cyclic cutting of silicon rod can greatly improve the cutting efficiency of bar, and the diamond particles attached to the surface of wire saw can also ensure the cutting surface quality of silicon rod. Therefore, the cutting equipment of brittle directly affects the development of semiconductors such as integrated circuits and solar photovoltaic [2].

At present, compared with the diamond wire saw production process of buried sand method and brush plating method, the suspension process has the characteristics of uniform sand and high efficiency of diamond wire saw [3]. By using one machine and multi-line saw production equipment, multiple wire saws can be produced at the same time, which greatly improves the production efficiency [4]. In the electroplating tank, multiple wire saws pass through the plating bath containing diamond powder, and the agitation pipe continuously replenishes the solvent into the upper sand tank and stirs continuously.

The quality of suspension electroplating diamond wire sawing process mainly depends on the dispersion degree of diamond powder in the electroplating tank, that is, the more uniform the distribution of diamond powder in the bath, the better the electroplating effect of the wire saw. At present, the structure of the agitation pipe is liquid feeding at one end, and the plating solution enters from one end of the agitation pipe, and then flows into the electroplating tank from multiple sandblasting ports. In the
production, it is found that sedimentation of diamonds in electroplating tank and uneven distribution of diamonds in coatings. Therefore, in order to overcome the problems of sand deposition and uneven sand coating in the production process of electroplated diamond wire saw, two kinds of agitation pipe are designed. In this paper, the fluid dynamics software will be used to analyze and compare the flow field in the electroplating tank under the action of different structure agitation pipes.

2 Setting of research methods

2.1 Agitation pipe.
As shown in Figure 1, the three structures are one end inlet type (a), middle inlet type-1 (b) and middle inlet type-2 (c), respectively. The third structure is added sandblasting ports at both ends on the basis of the second structure to realize the impact on the two walls of the electroplating tank. The length of each agitation pipe is 590mm and the liquid inlet diameter is 28mm.

2.2 Basic control equations.
The fluid in the electroplating tank is analyzed by FLUENT. Assuming that the electroplating tank is incompressible medium water, the fluid motion in the electroplating tank satisfies the fluid control equation [5],

\[ \nabla u = 0 \tag{1} \]
\[ \rho \frac{\partial u}{\partial t} = -\nabla P + \mu \nabla^2 u \tag{2} \]

2.3 Meshing and boundary condition setting.
As shown in Figure 2, the fluid domain of the electroplating tank corresponding to the one-end inlet agitation pipe structure is divided. The three kinds of agitation pipes adopt the same grid discrete form. The unstructured grid form is selected for discretization. The inlet of the agitation pipe is set as the velocity inlet with the value 3.4m/s. The electroplating tank on both sides of the outlet boundary conditions is set as pressure outlet with 0Pa. This outlet is also the position through which the diamond wire saw wire passes. The diamond wire saw wire forms the electroplated diamond wire saw through the micro-powder area. The other positions of the electroplating tank are set to the wall boundary condition. In data analysis, the plane \( x = -0.15 \text{m}, x = -0.30 \text{m}, x = -0.45 \text{m} \) and \( z = 0.022 \text{m} \) are established to collect the flow data.
3. Results and discussion

3.1 Plane flow field with z=0.022m.

As shown in Figure 3, the fluid velocity distribution in the electroplating tank under three kinds of agitation pipe structure can be clearly found that the different agitation pipe structure will lead to different fluid flow rules in the electroplating tank. The velocity of the sand blast mouth of the agitation pipe decreases gradually along the agitation pipe at one end, and a gradually decreasing velocity distribution is formed in the electroplating tank. The fluid in the pipe is ejected obliquely at the sandblasting mouth, and the fluid impinges obliquely on one side of the pool wall. In the middle area of the two agitation pipes, the opposite fluid impact will be formed and the middle flow field will be stirred. The fluid on the other side of the agitation pipe acts on one side of the pool wall thickness to flow along the pool wall, and the effect on the side wall gradually weakens, stirring the flow field in the pool.

Figure 3. Velocity distribution in Z plane in electroplating tank with three structures.

Compared with the water intake structure at one end, the sand blast velocity of the agitation pipe in the middle decreases from the middle to both ends, and the fluid flows obliquely out of the sand blast mouth, forming the trend of fluid impact to the walls on both sides. In the middle area of the two agitation pipes, the opposite impact of the fluid is formed on both sides of the wall, and the agitation of the fluid in the middle is formed after the action. The fluid at the outside of the agitation pipe impinges along the two walls, which acts on the side wall to form an opposite impact, and then acts on the middle flow field. Compared with the water intake structure at one end and in the middle, the fluid flow law in the electroplating tank is different, and the fluid velocity is not taken into account. From the point of view of the uniform flow field formed by the agitation law, the convection shock form of the two walls formed by the water intake structure in the middle is better than that on one side formed by the water intake structure at one end to avoid convection shock. In the middle inlet structure B, the fluid impinges on both sides of the agitation pipe and forms a "dead zone" of fluid flow at both ends. In the C structure, the sandblasting mouth at the end solves this phenomenon, hitting the two walls, so that there is no flow "dead zone" in the electroplating tank.

3.2 The x-plane flow field.

As shown in Figure 4, the velocity distribution in the x-plane of the electroplating tank under the three kinds of agitation pipe is shown. Compared with the middle inlet structure, it is found that in the
electroplating tank with water intake at one end, the fluid agitation is not obvious in the plane of \( x=-0.15 \) and \( x=-0.30 \), and the fluid velocity is relatively low in most of the middle areas. In the middle inlet structure electroplating tank, the fluid agitation in the three planes is relatively obvious, and there is little difference in the flow field distribution between B and C structures.

Figure 4. The \( x \)-plane velocity distribution in the sand sweeping tank with three structures.

3.3 Fluid velocity analysis of wire saw.
Figure 5 shows the fluid velocity distribution of the wire saw wire on the electroplating tank \( x=-0.15 \) m and \( x=-0.3 \) m to characterize the velocity distribution on the wire saw wire in the middle and on both sides, including the fluid velocity as well as the velocity in the \( z \) direction, a negative value means that the fluid is downward. On the whole, except for the special points at both ends of the wire saw wire, the fluid velocity on the same wire saw wire does not change much, and most of the positions where the fluid impacts the wire saw wire downward.

The fluid velocity distribution of each wire saw wire is calculated in Table 1. The calculation found that the fluid velocity on the wire saw wire under the central water inlet structure is significantly higher than that of the one end water inlet structure, on the plane \( x=-0.15, -0.3 \) and \( -0.45 \), The fluid velocity on the wire saw wire in the middle water inlet structure (A, B) is higher than that of the one end water inlet structure (137.93%, 134.48%), (20.45%, 34.09%) and (14.7%, -8.82%), respectively. The overall average is 57.70% and 53.25% larger, indicating that the central water inlet structure enhances the fluid agitation in the electroplating tank. In the electroplating tank with a water-inlet structure in the middle, the size of the fluid on the three wire saw wires is not much different. The difference between the largest and the smallest (A, B) is 47.17% and 15.25%, which is significantly lower than 134.48% of the water-inlet structure at one end. It shows that the water inlet structure in the middle enhances the uniformity of the fluid in the electroplating tank.

| X   | A          | B          | C          |
|-----|------------|------------|------------|
| -0.15 | 0.23         | 0.24         | 0.22         |
| -0.30 | 0.25         | 0.26         | 0.24         |
| -0.45 | 0.26         | 0.27         | 0.25         |

Figure 4. The \( x \)-plane velocity distribution in the sand sweeping tank with three structures.
Figure 5. Velocity distribution of flow on the wire saw.

Table 1. Velocity distribution of flow on the wire saw.

| Object                  | Structure                  | $x=-0.15$ | $x=-0.3$ | $x=-0.45$ |
|-------------------------|----------------------------|-----------|-----------|-----------|
| Average speed           | One end inlet type end     | 0.029     | 0.044     | 0.068     |
|                         | Middle inlet type 1        | 0.069     | 0.053     | 0.078     |
|                         | Middle inlet type 2        | 0.068     | 0.059     | 0.062     |
| Percentage of           | One end inlet type end     | 80%       | 80%       | 83.33%    |
| downward impact position| Middle inlet type 1        | 83.33%    | 50%       | 80%       |
|                         | Middle inlet type 2        | 73.33%    | 73.33%    | 70%       |
4. Conclusion
The fluid flow of three types of agitation pipes in the electroplating tank is analyzed by using FLUENT software, and the fluid flow in different planes of the groove and the position of the wire saw are compared. The relevant conclusions are as follows,

(1) The middle inlet type agitation pipe improves the fluid flow uniformity in the electroplating tank, and setting sand blasting ports at both ends of the agitation pipe can avoid the formation of fluid "dead zone" at both ends.

(2) In the electroplating tank along the direction of the agitation pipe, the fluid velocity in the middle part of the trough corresponding to the water intake structure at one end is on the low. The fluid agitation in the trough corresponding to the water intake structure in the middle part is more obvious in the three planes.

(3) The speed difference of the wire saw wire in the electroplating tank of the middle inlet type is 47.17% and 15.25%, which is significantly lower than that of the one end inlet type structure of 134.48%, indicating that the middle inlet type structure enhances the uniformity of the fluid in the electroplating tank.

Acknowledgement
This project is supported by National Natural Science Foundation of China (Grant No.51905211), China Postdoctoral Science Foundation (Grant No.2020M672128) and A Project of Shandong Province Higher Educational Youth Innovation Science and Technology Program (Grant No.2019KJB021).

Reference
[1] Luo Hui, Long Changjiang. (2017) Effect of the weight of nickel coated on diamond surface on performance of electroplated diamond wire saw. Electropating Finish., 36(16): 862-865.
[2] Ma Xiaobin, Ge Peiqi, Bi Wenbo, Meng Jianfeng. (2020) Simulational and experimental studies on flow rates at the blow holes of bath agitation pipe during composite electroplating for manufacturing of diamond wire saws. Electropating Finish., 39(3): 133-137.
[3] Wang Rui, Liu Xinkuan, Xu Bin, et al. (2017) Research status of preparation and application of electroplated diamond wire saw. Electropating Finish., 36(12): 660-664.
[4] Zheng Chuxi, Ma Xiaobin, Xie Qian, et al.. (2019) Experimental analysis on sawing performance of sand-suspension-electroplated wire saw. Diam. Abrasives Eng., 39(1): 76-79.
[5] Duan Derong, Ge Peiqi, Bi Wenbo, et al.. (2016) Numerical investigation on the heat transfer enhancement mechanism of planar elastic tube bundle by flow-induced vibration. Int. J. Therm. Sci., 112: 450-459.