

Research status of metal bipolar plate connection and deformation control

Abstract

The bipolar plate is one of the core components of the fuel cell. The connection of the bipolar plate and the deformation after connection are important factors affecting the quality of the bipolar plate. In order to improve the performance and service life of the fuel cell, it is necessary to enhance the corrosion resistance of the connection and reduce the deformation of the bipolar plate after connection.

Key words: plate connection, bipolar plate, core components

1 INTRODUCTION

Fuel cell is the fourth power generation technology after hydropower generation, thermal power generation and atomic power generation. Fuel cell has high power generation efficiency and low environmental pollution. The hydrogen fuel cell is not limited by the thermal efficiency of the Carnot cycle, and the energy conversion efficiency can easily exceed 60%. As one of the vehicle power, it is far higher than the combustion engine. Bipolar plates play a role in evenly distributing gas, collecting current, cooling and supporting in fuel cells. At present, bipolar plate materials mainly include graphite, metal and composite materials. Graphite is the first material to be used as a bipolar plate. It has good corrosion resistance and conductivity. However, its brittleness is high, mechanical strength is low, and it is easy to break during use, which can not meet the further requirements of the bipolar plate. Because metal bipolar plates meet the advantages of thin wall, light weight, high dimensional accuracy, small size, low manufacturing cost, etc., they have become one of the main development directions of hydrogen fuel cells in recent years. As shown in Figure 1, metal bipolar plate mesh model was established using abaqus.

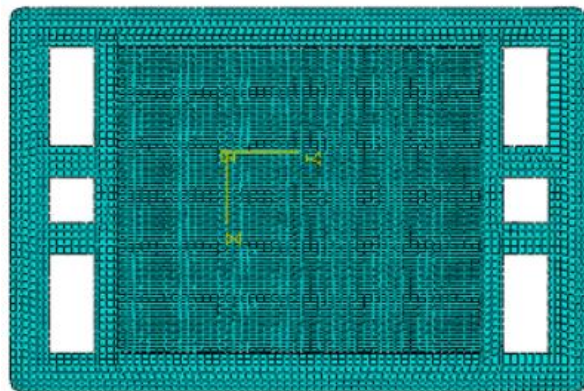


Fig.1 Metal bipolar plate mesh model

The metal bipolar plate is connected by ultra-thin stainless steel monopole plate with complex flow channel structure. The change of connection mode and process parameters will have an important impact on the shape error and joint performance of the bipolar plate. Therefore, the welding of the metal bipolar plate is one of the important factors affecting the quality of the metal bipolar plate [1]. There are many kinds of welding, including laser welding, laser adhesive welding, adhesive welding, soft soldering and brazing. The ultimate purpose of these welding is to reduce the deformation and residual stress of the welded bipolar plate. Because the metal electrode plate is made of ultra-thin stainless steel plate and is sensitive to welding parameters, the local part of the joint is easily warped under the action of welding heat input, resulting in the separation of the upper and lower metal electrode plates. Because laser welding belongs to non-contact welding, the separation of the upper and lower metal plates will lead to the failure of heat transfer to the lower plate, so the metal bipolar plates must be held by the precision welding fixture during the welding process. Due to the structural requirements of the plate type, the space available for clamping is very small and the metal plate structure is complex, so it is difficult to ensure that all areas are tightly clamped. In the actual welding process, there will be weld through and faulty welding [2], and the welded bipolar plate will produce deformation and residual stress, which will affect the assembly of fuel cells and thus affect the life and performance of fuel cells [3]. Therefore, the study of bipolar plate welding is of great significance to the improvement of fuel cell performance and the extension of its life. As shown in Figures 2 (a), 2 (b), and 2 (c), there are three main types of deformation of metal bipolar plates after welding: Lateral shrinkage deformation after welding, corner deformation after welding, and arch deformation after welding.

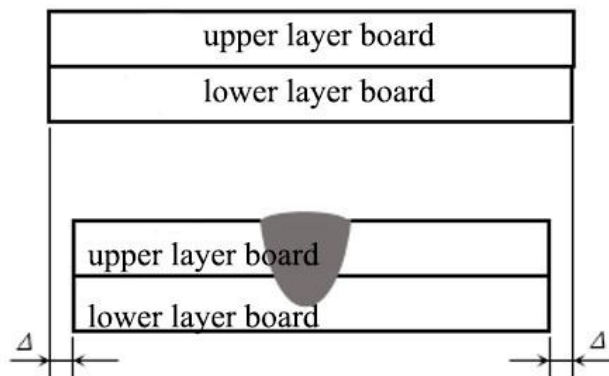


Fig2(a) Lateral shrinkage deformation after welding

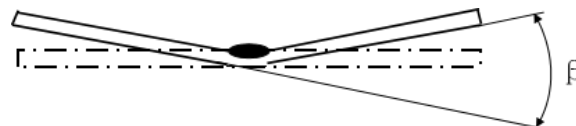


Fig.2(b) Corner deformation after welding

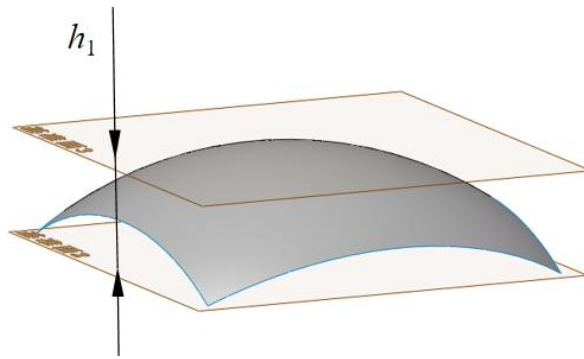


Fig.2 (c) Arch deformation after welding

2 Research status of laser welding of metal bipolar plates

2.1 Research status of laser welding of metal bipolar plates abroad

Vicente Afonso Ventrella [4] et al. studied the effect of pulse energy on the weld characteristics of ultra-thin stainless steel during laser lap welding of 0.1mm thick ultra-thin stainless steel. In the study, the pulse energy was changed from 1.0 to 2.25 J in increments of 0.25 J, and the pulse duration was 4 ms. The weld was analyzed by optical microscope, tensile shear test and microhardness. The results show that the ultimate tensile strength of welded joints first increases and then decreases with the increase of pulse energy. And the process is very sensitive to the distance between the two plates. Pulse energy control can ensure the good mechanical properties of the welded joint and reduce the discontinuity of the welded joint.

Patrizia Perulli [5] et al. established a simulation model for the hybrid laser-MAG (metal active gas) welding process of duplex (DP) steel and austenitic stainless steel (AISI316). The simulation model was established using Simulate Welding. The heat source coupled two different models to simulate the heat input of laser and electric arc. At the same time, the continuous cooling transformation (CCT) diagram and the calculated cooling rate were used to evaluate the metallurgical transformation of DP steel. The reliability and correctness of the simulation model are verified by the weld shape, thermal cycle and geometric deformation of the butt weld.

Partha Saha [6] and others tried to characterize the LBW process for joining sub-millimeter thick SS 316 sheets. For this purpose, a Y-fiber laser with a power of 2 kW is used. A thickness of 0.2 mm was welded in a butt joint. The responses considered are ultimate tensile strength, weld width and microhardness. The analysis of the variance of the selected quadratic model shows that the model can fully predict the correct results within the selected range. The analysis of microstructure, fractal and tensile behavior clearly shows the influence of base material composition and heat input on welding quality. The input parameters are optimized to provide the highest tensile strength and the minimum welding width, which are confirmed by the validation experiment.

Suman Chatterjee [7] et al. carried out experimental research on laser butt welding using pulsed Nd: YAG laser. Specifically, the effects of laser parameters such as laser current, pulse width and scanning speed on the welding quality of 0.45 mm thin plate were studied. In addition, the mechanical characterization of the welding path is carried out by evaluating and measuring the

microhardness, residual stress, surface roughness and welding strength. The research shows that laser current is the most important parameter in sheet metal welding. The welding strength increases to a certain level with the increase of scanning speed, and then decreases. Point overlap will seriously affect the surface integrity (surface roughness) and welding strength of welded joints. The microhardness of the melting zone (FZ) is higher than that of the heat-affected zone (HAZ), which is due to the difference in grain structure (coarseness) caused by the cooling rate. The research also shows that the laser pulse energy has a significant effect on the generation of residual stress in welded joints.

Nikhil Kumar [8] and others used the empirical model developed by RSM to study the effects of laser power, scanning speed and pulse width on the ultimate tensile strength and welding width. In addition, the microstructure analysis, hardness and tensile properties of the selected 304SS and 316SS welds have been carried out to understand the metallurgical and mechanical properties of the welds. The results show that compared with the high energy input pulsation, the low energy input pulsation usually produces fine grain structure and improved mechanical properties, which is independent of the substrate composition. However, under the given parameters, 304SS has better microstructure and mechanical properties than 316SS.

M. Zain-Ul-Abdein [9] and others studied the thermo-mechanical response of aluminum alloy 6056T4 used to manufacture fuselage panels to laser beam welding under complex industrial boundary and load conditions. The single-pass fusion welding of laser beam was carried out on several test plates. Thermocouples were used to record the temperature history, and the geometric shape of the weld was checked through macroscopic inspection. At the same time, the displacement field was observed through 3D image correlation technology. Then Abaqus was used for decoupling thermodynamic analysis, and the simulation results were compared with the experimental results. Good agreement was found between the simulation results and the experimental results.

KIMT [10] et al. studied the hybrid welding process combining TIG arc welding with YAG laser. During the research, it was confirmed that the emission position of the laser beam is very important for obtaining good welding in hybrid welding. Therefore, a new intelligent system using visual sensors to monitor the welding area is constructed. In addition, a control system that emits the laser beam to the selected position in the molten pool is constructed, which is formed by TIG arc. The results of welding experiments using these systems show that the hybrid welding process and control system are effective for the stable welding of thin stainless steel plates.

P Pankaj [11] and others carried out experiments and numerical analysis on CO₂ laser welding of AISI 304 stainless steel plate with a thickness of 1 mm. It is very important to predict the transient thermal history when designing welded joints. A 3D finite element (FE) model was developed using ANSYS to determine the influence of welding process parameters (i.e. laser power and welding speed) on the thermal history of laser welded joints. The results show that the cooling rate is greatly affected by the changes of laser power and welding speed. Increasing laser power and reducing welding speed will increase the size of fusion zone and heat affected zone. The transient thermal analysis results and experimental results obtained from the finite element model are well verified, and the maximum percentage error of peak temperature is 6.47%.

MIS Ismail [12] et al. established a three-dimensional finite element model to simulate the temperature, stress and deformation fields in continuous wave (CW) laser micro-welding of stainless steel sheet. The application of the developed thermal model shows that the laser

parameters have a significant impact on the temperature field and weld pool. During heating and cooling, plastic deformation will produce welding stress and deformation. The numerical simulation results show that the developed finite element model can effectively predict the thermal cycle, thermal stress and welding deformation of thin materials.

2.2 Research status of laser welding of metal bipolar plates in China

Li Jianqiang [13] studied the influence of welding power, welding speed, defocus and other process parameters on weld penetration width, weld penetration depth, waist width and waist height through the method of quadratic regression universal rotary combination design, obtained the corresponding regression equation and conducted the significance test of the regression equation, the significance test of the regression coefficient, and the fitting test of the regression equation; Using the obtained regression equation, the single-factor influence study, the two-factor influence study and the three-factor optimal result study were carried out to determine the optimal results under different conditions. Finally, the laser welding process is simulated by using ansys software.

Zhang Wei zhe [14] studied the influence of laser welding process parameters such as laser power, laser pulse width, laser speed and defocusing amount on the welding quality of 0.3mm thick 304 stainless steel through welding experiments, and measured the microstructure, tensile strength and hardness of the welded joint. Finally, the distribution law of the welding temperature field was explored using simulation method.

Zhang Jing yi [15] studied the buckling deformation of 0.07mm thick 316L stainless steel sheet. First, the inherent strain of laser welding of 316L stainless steel sheet was obtained by simulation method, and then the eigenvalue buckling analysis of the buckling deformation of the sheet was carried out using the inherent strain obtained. Finally, the nonlinear buckling analysis of the buckling deformation of the sheet was carried out. The analysis results showed that the critical buckling load of the sheet was negatively correlated with the area of the sheet, And has a positive correlation with the thickness of the thin plate.

Li Qi bo [16] et al. studied the process method of pulse laser butt welding of 0.2mm thick 1Cr18Ni9Ti, and optimized and analyzed the process parameters that affect the welding quality: welding current, pulse width and pulse frequency using three factors and three levels of orthogonal experimental method. The evaluation index of the experiment is the tensile strength of the welded joint. The optimization results show that the maximum tensile strength can be obtained with 82A welding current, 2.0ms pulse width and 22Hz pulse frequency.

Ou yang Yi [17] and others observed and measured the microstructure, microhardness, tensile strength and tensile fracture morphology of A286 under specific laser welding process. The results show that under the condition of laser power 740W, welding speed 0.45m/min, wire feeding speed 0.75m/min, defocusing distance 15mm, gap 0.1-0.4mm, the hardness of the heat-affected zone and weld zone of the welded joint is larger than that of the base metal zone, and there are a lot of dimples at the tensile fracture of the welded joint, which is a typical ductile fracture form.

Du Xiang yong [18] and others explored the feasibility of single-mode laser welding 316L stainless steel ultra-thin plate and the advantages of single-mode laser welding by comparing the process of single-mode and multi-mode laser welding 0.1mm thick 316L stainless steel ultra-thin plate. The results show that the single-mode fiber laser can realize the effective connection of

316L stainless steel ultra-thin plate when the power is 40W, and the weld width is narrower and the welding deformation is smaller.

Ye Qing feng [19] and others studied the lapping pulse laser welding process of 321 stainless steel sheet with a thickness of 0.1 mm, optimized the welding process by orthogonal test method, and analyzed and tested the microstructure and mechanical properties of the welded joint. The results show that the maximum shear load of the welded joint is 94% of the tensile force of the base metal, and the microhardness value of the weld zone is higher than that of the base metal when the optimum process parameters are welding speed 0.5 m/min, laser power 150 W, and defocusing distance+2 mm.

Because the material of ultra-thin stainless steel is very thin, and it is very easy to vaporize and perforate, the key is to have accurate control of parameters in order to obtain continuous and non-burnthrough welds. He Dong wei [20] et al. realized the butt welding of 0.22mm thick 321 stainless steel sheet by using micro-laser, and then optimized the process parameters to a certain extent through orthogonal optimization design, so as to carry out research on the influence of process parameters on the microscopic morphology of welded joints.

Wu Xiao hong [21] et al. used a wavelength of 1.06 μ M Nd: YAG laser was used for laser sealing welding of ultra-thin stainless steel sheet with a thickness of 0.08 mm. The ultra-thin stainless steel sheet was successfully welded by pulse laser by adjusting the frequency, pulse width, welding speed, defocusing amount and other process parameters of the pulse laser. This paper focuses on the influence of welding spot overlap rate on weld seam sealing, and discusses in detail the main factors affecting the spot overlap rate: the relationship between pulse frequency, welding speed, and spot size.

3. Advantages and disadvantages of metal bipolar plates and solutions

3.1 Advantages of metal bipolar plate

At present, the bipolar plates developed mainly include graphite carbon plates, composite plates and metal plates. Graphite is the first material to be used as a bipolar plate. It has good corrosion resistance and conductivity. However, its brittleness is high, mechanical strength is low, and it is easy to break during use, which can not meet the further requirements of the bipolar plate. In order to make up for the shortage of graphene bipolar plates, researchers are vigorously developing composite and metal bipolar plates and applying them to hydrogen fuel cells to gradually replace the market occupied by graphene bipolar plates. Compared with the other two kinds of bipolar plates, the metal bipolar plates are solid and durable, with good machining performance, good conductivity, good thermal conductivity and good compactness. Moreover, the thin metal bipolar plate is the most competitive electrode material, which is easy to realize mass production, reduce the cost of the stack, and greatly improve the specific power of the stack. Therefore, it has attracted the attention of many researchers.

3.2 Disadvantages of metal bipolar plate

Since the environment where the bipolar plate is located has both oxidizing and reducing media, the metal bipolar plate must solve two problems [22]. The first is to prevent metal surface

passivation in oxygen-enriched environment from increasing contact resistance; The second is to prevent corrosion under acidic conditions within the working potential range. In addition, because metal bipolar plates need to meet the conditions of thin wall, light weight and high dimensional accuracy, the research on the plastic forming process of metal bipolar plates has also attracted extensive attention of scholars at home and abroad. Because the metal electrode plate is made of ultra-thin stainless steel plate and is sensitive to welding parameters, the local part of the joint is easily warped under the action of welding heat input, resulting in the separation of the upper and lower metal electrode plates. Because laser welding belongs to non-contact welding, the separation of the upper and lower metal plates will lead to the failure of heat transfer to the lower plate, so the metal bipolar plates must be held by the precision welding fixture during the welding process. As shown in Figure 3, laser welding was carried out without the use of fixtures. From the figure, it can be seen that the two stainless steel plates were separated, and the deformation of the upper plate was very large. In the actual welding process, due to the influence of process parameters such as welding power and welding speed, stainless steel plates may experience welding penetration and virtual welding, as shown in Figure 4. Due to excessive welding power, stainless steel plates may experience welding penetration. Moreover, the welded bipolar plate will produce deformation and residual stress, which will affect the assembly of fuel cells and thus affect the life and performance of fuel cells.



Fig.3 Laser welding of stainless steel plates without using fixtures



Fig.4 Stainless steel plate welding through

3.3 Treatment measures

Optimize welding process parameters. The welding process parameters of metal bipolar plate include welding power, welding speed, preheating temperature, turning radius, etc. Under the

condition that there is no false welding and welding penetration, the range of welding process parameters of metal bipolar plate is simulated by single factor experiment method, and the values of each process parameter are taken according to a certain rule, and then the orthogonal experiment is carried out to find the optimal solution for welding deformation of metal bipolar plate. As shown in Figure 5, the optimal temperature cloud map of the weld cross-section was obtained by using Abaqus for laser welding simulation. After extensive simulation and comparison, it is known that when the welding power $Q=75w$, welding speed $V=100mm/s$, and the preheating temperature of stainless steel plate $T=40\text{ }^{\circ}C$, the molten pool is relatively optimal and the deformation is relatively small, as shown in Figure 6.

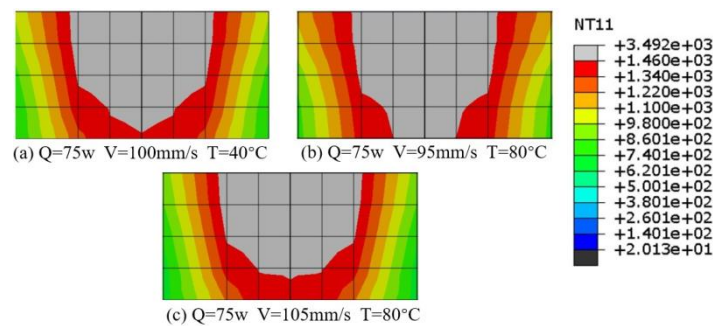


Fig.5 temperature cloud map of weld cross-section

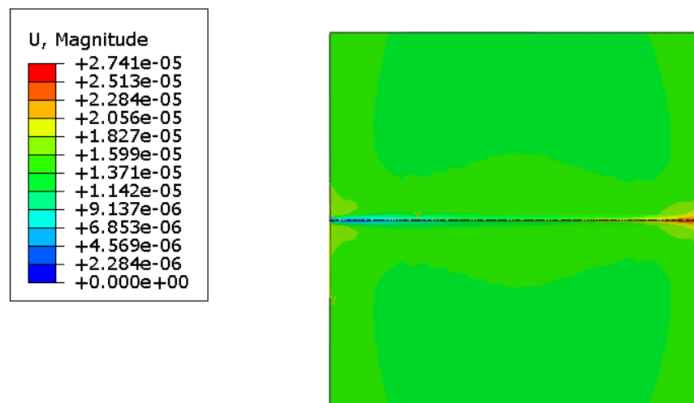


Fig.6 $Q=75w$, $V=100mm/s$, $T=40\text{ }^{\circ}C$ deformation cloud map

Optimize the welding position and path. In the process of laser welding, the position of the anode plate and the cathode plate will also affect the deformation of the bipolar plate after welding. For example, during the welding process, the anode plate is welded on the cathode plate first, and when the welding reaches a certain stage, the anode plate and the cathode plate are turned over, that is, the cathode plate continues to be welded on the anode plate, and the anode plate is welded on the cathode plate until the end. After these two kinds of welding, The deformation degree of bipolar plates is different. Secondly, the welding path will also affect the deformation of the bipolar plate after welding. There are many lines to be welded for the metal bipolar plate, so where to start welding first and where to finish welding need to be considered. At present, Liu Feng [23] and others proposed a welding method, which is to weld the middle part of the plate, then the secondary periphery of the plate, then the secondary middle of the plate, and finally the outermost

periphery of the plate. The welding results show that the warpage of the metal bipolar plate welded by this method can be kept between 1mm and 2mm. Figure 7 is Geometric model of metal bipolar plate. The red line represents the welding path

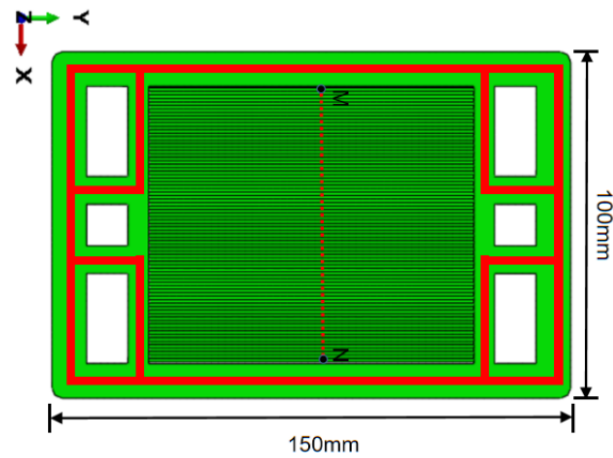


Fig.7 Geometric model of metal bipolar plate

Design a set of welding fixture. In the process of metal bipolar plate welding, the welding fixture is required to hold the bipolar plate before welding. Because the thickness of the metal bipolar plate is only 1mm or even thinner, the deformation of the bipolar plate is larger than that of the thicker plate when clamping the metal bipolar plate, so it is very important to design a more precise welding fixture. Figure 8 is a schematic diagram of the self-designed air flotation fixture clamping.

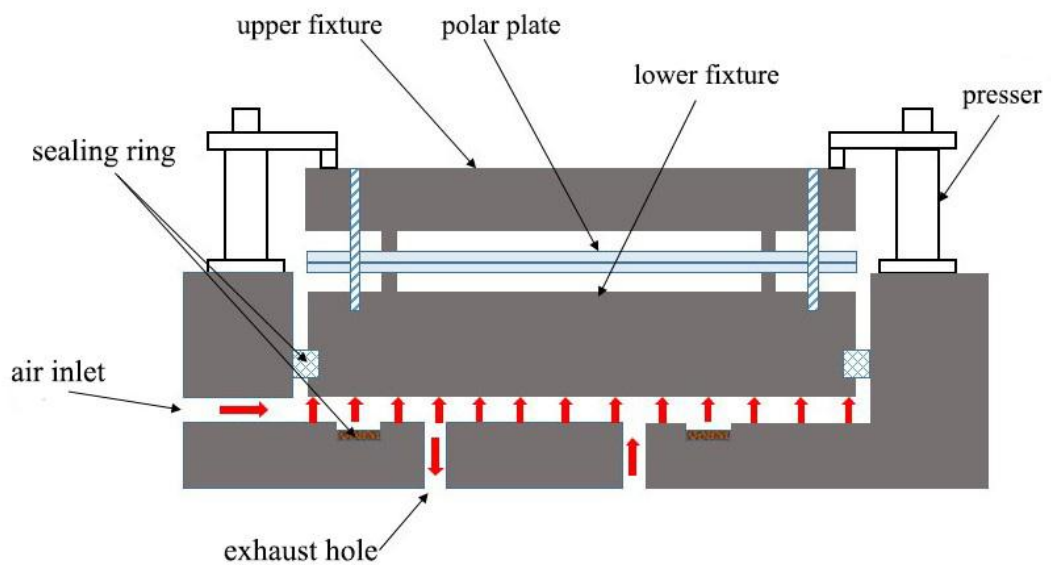


Fig.8 Schematic diagram of air flotation clamp clamping

4. Conclusion

Laser welding is an important part of metal bipolar plate manufacturing process. The

determination of proper laser welding process parameters, clamping parameters, welding path and structure parameters of bipolar plate runner is the premise to improve the welding quality of metal bipolar plate. In this paper, solutions are proposed for how to measure the laser welding process parameters and how to plan the welding path, but no specific solutions are proposed for the clamping parameters of the fixture. Moreover, the structural parameters of the flow passage of the bipolar plate will also have some influence on the welding quality, such as ridge width, ridge height, wall thickness and other parameters. These parameters will affect the deformation degree of the bipolar plate after welding, but at the same time, the change of these parameters will affect the chemistry of air and hydrogen, thus affecting the performance of the bipolar plate. Therefore, a lot of simulations and experiments are needed to change the structural parameters of the flow channel.

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