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Research on the Electropolishing Process of Stainless Steel by Brush

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Abstract

The brush electropolishing process is the actual industrial production of equipment used in the currently limited reference, to guide future industrial production, brush electropolishing experiments on SUS 304 stainless steel plates, first selected the liquid flow, after the use of the single-factor method were studied different current density, polishing time, temperature three process parameters on SUS 304 stainless steel after electro-polishing treatment. The effect of the surface quality of SUS 304 stainless steel after electropolishing was investigated using a single-factor method, and the difference in roughness Ra before and after electropolishing was used to determine the optimum process parameters. Based on the single-factor results, orthogonal experiments were carried out to find that the influence of each process parameter on the difference in roughness was ranked as current density > temperature > polishing time. The final results show that when the current density is 42 A/dm2, the electrolyte temperature is 50 °C and the polishing time is 105 s, the surface quality of the sample after electro-polishing is very good and the final roughness is 0.064 μm, which is mirror bright and the corrosion resistance is greatly improved compared to that before electropolishing, which provides a basis for the use of the brushing process in the future.

Keywords

Stainless Steel; Electropolishing; Surface Treatment; Electro-brushing; Corrosion Resistance.

1. Introduction

Stainless steel materials are used in a wide range of industrial scenarios, such as the semiconductor industry, biomedical science, and the manufacture of automotive components, for their excellent mechanical and corrosion resistance [1–4]. With stainless steel, the ability to be used for long-term applications is both economically and safely important. Given this, various industries have placed higher demands on the surface properties of stainless steel.

Electropolishing technology as an effective metal surface treatment technology can obtain a high surface finish [5] and can produce a passivation film of uniform chemical composition on the metal surface [6], greatly improving the corrosion resistance of stainless steel [7], Widely used for stainless steel surface treatment. The stainless steel brush electropolishing process is also known as friction electropolishing. The process is suitable for the electropolishing of stainless steel surfaces of large equipment that cannot be treated in an electrolytic bath, such as mixing equipment and non-standard chemical equipment, including the inner surfaces of heads and the outer surfaces of internal components [8]. Due to the novelty of this friction electropolishing process, the equipment is also relatively simple and suitable for industrial production handling large equipment with low production

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costs, In recent years, frictional electropolishing techniques have also received increasing attention [9].

However, there is no literature available for brush polishing, All studies are based on slotted equipment [10–12]. Therefore, this paper uses SUS 304 stainless steel as the experimental material and adopts the brush-type process, which is rarely seen in current research, to explore the influence of different process parameters on the difference of surface roughness Ra before and after electropolishing using single-factor experiments, and to design orthogonal experiments based on the results of single-factor experiments to determine the influence of process parameters on the roughness Ra ranking, to lay the foundation for future stainless steel brush-type electropolishing process.

2. Experiment and Methods

2.1 Experimental Materials and Reagents

The material used for this experiment was a commercial SUS 304 stainless steel plate with the elemental content shown in Table 1. The plate was cut to a fixed size (100mm×100mm×3mm) using laser cutting, and a part of the area was protected with protective film leaving a polished area (100mm×50mm), then 80 mesh, 120 mesh, 240 mesh, 400 mesh, and 600 mesh sandpaper was used to remove the surface oxide film and burrs, and then the surface was cleaned with alcohol to remove grease and blown dry. The purity of reagents used in the experiments was all analytically pure. H_3PO_4:H_2SO_4 = 4:1 (v/v) was used as the electropolishing solution.

Table 1. Chemical composition of SUS 304 stainless steel

Element	C	Mn	P	S	Si	Cr	Ni	Fe
Content/%	0.08	2	0.045	0.03	1	19	9	Bal.

2.2 Experimental Equipment

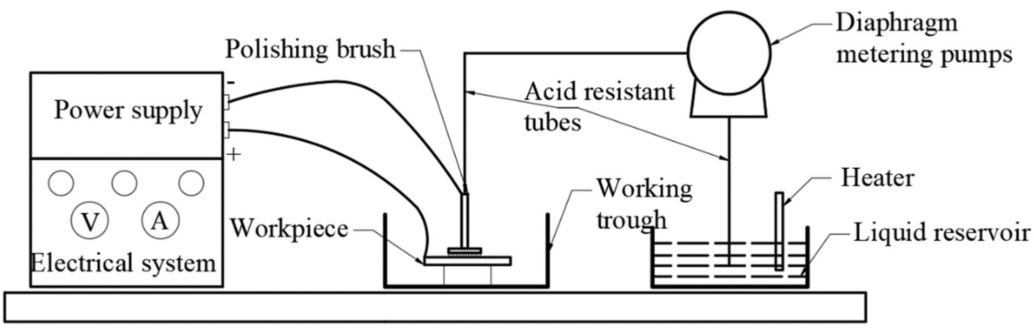

Figure 1. Electropolishing experimental equipment

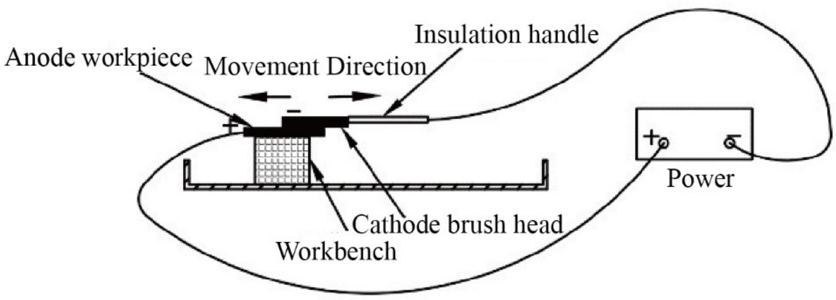

Figure 2. Diagram of operation

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The experimental equipment is designed in-house, the schematic diagram of the equipment is shown in Figure 1 and its general working process is shown in Figure 2. The operation is carried out with the brush head moving back and forth on the surface of the material for electropolishing, with pores on the surface of the cathode brush head being pumped out from the reservoir through a pipe from the brush head using a diaphragm pump.

2.3 Experimental Research Methods

Firstly, a single-factor experimental method was used to explore the effect of current density, electropolishing time, and electrolyte temperature on the difference in roughness Ra at different levels by varying different process parameters and using the difference in roughness Ra before and after electropolishing as a measure, in addition to this, the diaphragm pump flow rate and brush speed were studied to explore the results of their effect on surface roughness. The experimental factor levels are shown in Table 2. After determining the process parameters, a three-factor, the three-level orthogonal experiment was designed based on the results of the single-factor experiment to determine the effect of each experimental parameter on the roughness Ra difference and to determine the optimum process combination.

Due to the large area of the sample used, the results were represented by testing the roughness at six different points on the sample surface and taking the average value, and finally taking the difference in roughness Ra before and after electropolishing to explore the results. The locations of the roughness test points are shown in Figure 3 at A, B, C, D, E, and F.

Table 2. Table of experimental factor levels

Current density/(A/dm^2)	Temperature/°C	Time/s
36	30	60
38	35	75
40	40	90
42	45	105
44	50	120
46	55	135
48	60	150
—	65	—
—	70	—

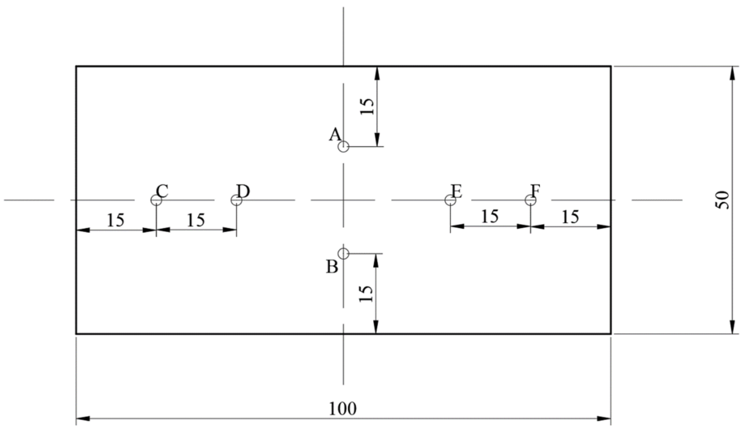

Figure 3. Roughness detection point

2.4 Experimental Apparatus

Mitutoyo SJ210 roughness tester: measuring material surface roughness; SMN60 gloss tester: measuring material surface gloss after electropolishing; laser cutting machine: cutting samples; JSM-6510LA scanning electron microscope (SEM): analyzing material surface morphology before and after electropolishing; Tatsuwa CHI660E electrochemical workstation: testing material surface corrosion resistance.

3. Experimental Results and Discussion

3.1 Selection of the Power of the Diaphragm Metering Pump

The power of the diaphragm pump will directly affect the flow of electrolytes. When the power of the diaphragm pump is higher, the outflow of the electrolyte will be higher; when the power of the diaphragm pump is lower, the outflow of the electrolyte will also be reduced. The amount of electrolyte outflow will affect whether the brush and plate can be filled with electrolytes, so the diaphragm pump flow size should be reasonably selected. In this experiment, the diaphragm pump flow rate was adjusted at a current density of 42 A/dm^2, polishing time of 105 s, and room temperature (25 °C). The results are shown in Figure 4. In this experiment, the surface of the specimen is pretreated by mechanical polishing to 600#, the main process parameters are room temperature (25 °C), current density 42 A/dm^2, and polishing time 105 s. Under these conditions, the effect of different diaphragm pump power, i.e. different polishing fluid flow rates on the surface roughness of the specimen is studied.

The diaphragm metering pump does not flow out of the electrolyte at 0% power so the metering pump power was chosen to be tested at 5% to 35% intervals. Figure 4 shows the test results for each roughness criterion. From the results of the roughness Ra test in Figure 4 (a), it can be seen that as the power of the diaphragm pump increases, the roughness Ra value decreases after electropolishing, at 20% diaphragm pump power the final roughness Ra decreases to 0.084 μm, thereafter as the power of the diaphragm pump continues to increase the final roughness also basically stops changing, at 35% power the final roughness rises slightly but compared to this phenomenon is probably due to the fact that the initial roughness of the specimen before electropolishing is slightly higher when the power is 35%, so the difference in the final roughness Ra goes to see, in fact, after the power exceeds 20%, with the increase in the power of the diaphragm pump, the efficiency of electropolishing is not improved, so this paper selected the power of the diaphragm pump for 20%, both to ensure that Electropolishing efficiency is improved, but also to ensure that the flow of polishing solution will not waste too much, increase the polishing solution recovery time, improve efficiency.

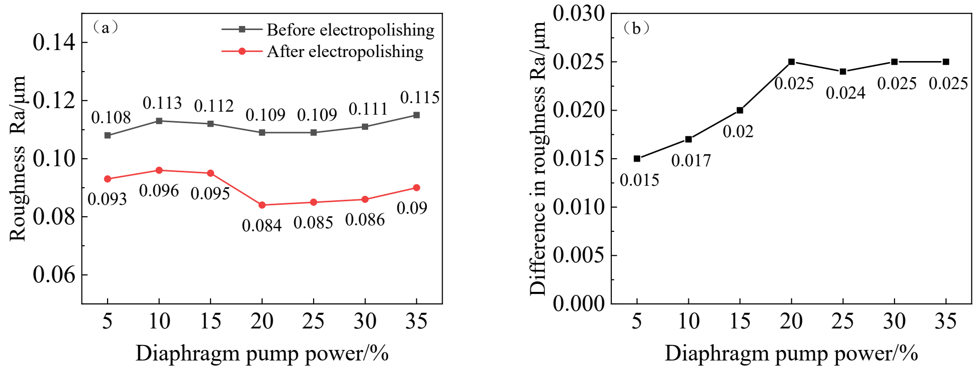

Figure 4. Roughness changes curve with diaphragm pump flow: (a) Roughness before and after electropolishing; (b) Roughness difference curves

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3.2 Analysis of the Results of the One-way Experiment

3.2.1 Effect of Current Density on Surface Roughness

The results of electropolishing experiments at a temperature of 50 °C and a polishing time of 105 s at different current densities are shown in Figure 5, from which it can be seen that with the gradual increase in current density, the difference in roughness Ra before and after electropolishing shows a trend of first increasing and then decreasing. This is because the removal effect on the metal surface is limited at a lower current density and the efficiency is relatively low. With a suitable increase in current density, the electropolishing process can be carried out normally, and the amount of metal surface removal increases. However, when the current density is increased beyond 42A/dm^2, the polishing speed is accelerated, and the oxygen is release from the surface of the anode [13].

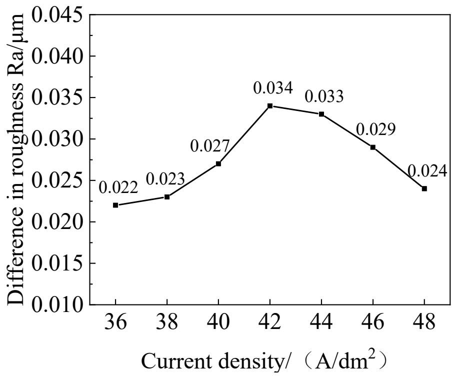

Figure 5. Variation curve of roughness difference with current density

3.2.2 Effect of Different Times on Roughness

As shown in Figure 6, at a temperature of 50 °C and a current density of 42 A/dm^2, the difference in roughness before and after electropolishing gradually increases as the polishing time increases, with the maximum decrease in roughness at 105 s, after which the decrease in roughness begins to decrease as the time continues to be extended, i.e. the highest efficiency of electropolishing is achieved at 105 s. When the time is short, the electropolishing process is not completely carried out, and the height difference between the microscopic projection and depression of the material surface is still in the process of decreasing, as the time increases, the electropolishing process continues, the height difference between the microscopic projection and depression of the material decreases, and the material surface begins to tend to be flatter. However, too much time will lead to the metal surface will produce pitting and etching pits, the surface quality decreased, and electropolishing quality decreased, resulting in lower efficiency [14].

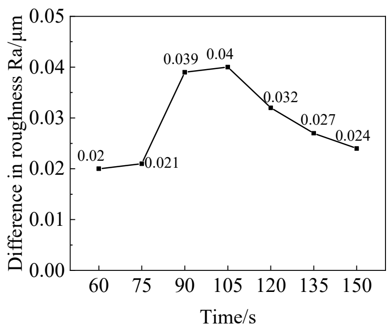

Figure 6. Roughness difference curve with time

3.2.3 Effect of Different Temperatures on Roughness

It can be seen from Figure 7 that at a current density of 42 A/dm^2 and a polishing time of 105 s, the roughness difference gradually increases as the temperature increases, peaking at 50 °C, representing the best electropolishing effect at this temperature, then as the temperature continues to increase, the

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roughness difference begins to decrease. This is because when the temperature of the electrolyte is low, the greater viscosity of the electrolyte leads to a slower diffusion of dissolved metal ions, which in turn leads to an incomplete electropolishing reaction and a lower amount of roughness reduction [15]. With a slow increase in temperature, the electropolishing process is improved to a limited extent. When the temperature is too high, the viscosity of the electrolyte decreases and the diffusion of metal ions accelerates, promoting the accelerated dissolution of raised and depressed positions on the microscopic surface of the material. When the electrolyte temperature is too high, the electrochemical process becomes very violent, which is accompanied by the electrolytic process itself, which generates heat and leads to an accelerated dissolution of the metal and the production of a large number of bubbles on the surface, which may seriously lead to the start of etch pits on the metal surface, making The polished surface finish decreases and the surface roughness rises slightly [15].

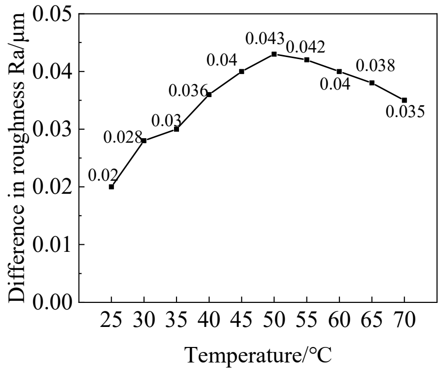

Figure 7. Variation curve of roughness difference with temperature

3.3 Analysis of Orthogonal Results

Table 3. Results of orthogonal tests

Experiment number	Current density/(A/dm^2)	Temperature/°C	Time/s	Difference in roughness Ra/μm
1	36	30	60	0.018
2	36	50	105	0.022
3	36	70	150	0.017
4	42	30	105	0.023
5	42	50	150	0.026
6	42	70	60	0.020
7	48	30	150	0.017
8	48	50	60	0.019
9	48	70	105	0.018
K1	0.057	0.058	0.057	
K2	0.069	0.067	0.063	
K3	0.054	0.055	0.060	
k1	0.019	0.019	0.019	
k2	0.023	0.022	0.021	
k3	0.018	0.018	0.020	
R	0.005	0.004	0.002	

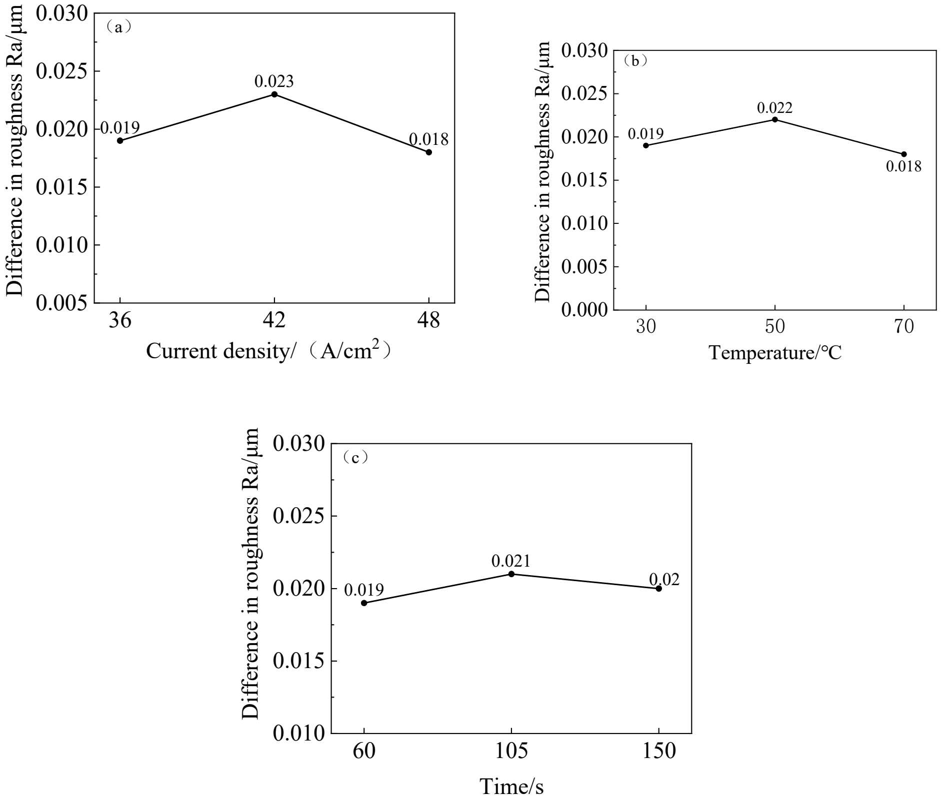

Figure 8. Diagram of the effect of different process parameters on the roughness difference:(a)Current density effect; (b)Temperature effect; (c)Time effect

According to the influence of each process parameter on the surface roughness Ra in the above single-factor experiment, the values of each level of the orthogonal experiment were selected and the final experimental results were obtained as shown in Table 3. Figure 8 shows the trend of the amount of roughness reduction under each process parameter after the orthogonal analysis. It can be seen from the graph that the influence of each process parameter on the roughness difference before and after electropolishing of the material remains the same as that of the single-factor experiment, i.e. the optimum process parameters are current density 42 A/dm^2, electrolyte temperature 50 °C and electropolishing time 105 s. The extreme difference values R for current density, electrolyte temperature, and electropolishing time are 0.01, 0.006, and 0.003 respectively, therefore the influence of the process parameters on the roughness difference is in the order of current density > electrolyte temperature > electropolishing time.

3.4 Surface Morphology and Electrochemical Analysis

3.4.1 Surface Appearance

The material was electrolytically polished at optimum process parameters and the surface of the polished material was compared with the surface of the material sandpapered to 600# before electropolishing to observe the surface morphology of the material. The SEM (Scanning Electron Microscope) images of the different surfaces are shown in Figure 9. It can be seen from the images that after polishing, the surface of the material can be seen to have consistent scratches in the same direction and there are no defects such as pits or bumps on the surface of the sample.

The sample was tested for roughness and the amount of roughness reduction was 0.038 μm, with a final surface roughness of 0.064 μm. Using a gloss meter to test the sample, it was found that the surface gloss after electropolishing reached 549 GU, which can reach a mirror finish, as shown in Figure 10. It can be seen that electropolishing can significantly improve the surface morphology of

304 stainless steel, reduce its surface roughness and improve its surface gloss value, to get a perfect surface polishing state.

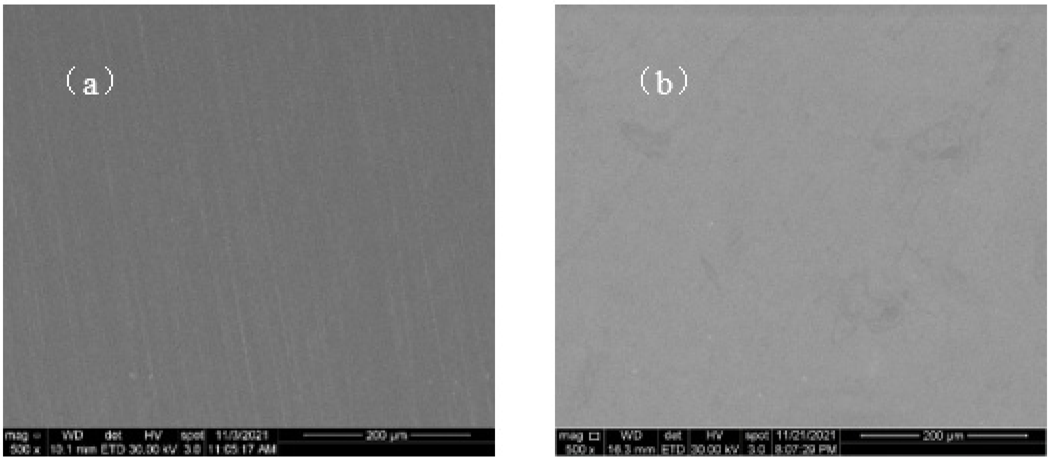

Figure 9. SEM images of sample surfaces: (a) polished surface; (b) electropolished surface

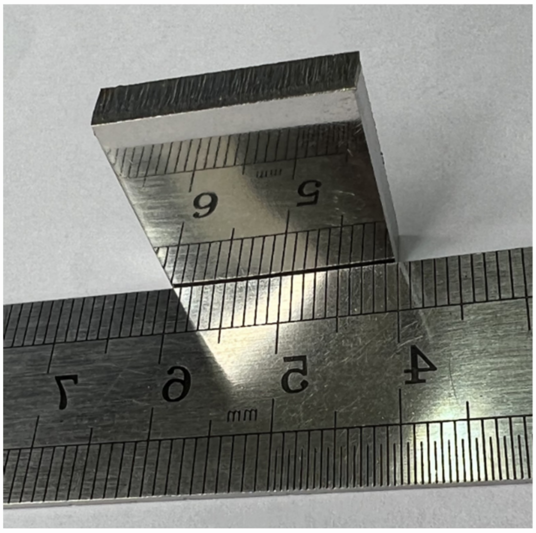

Figure 10. Specimen gloss

3.4.2 Electrochemical Testing

Figure 11(a) shows the open circuit potential of the samples in 3.5% NaCl solution after sandpaper sanding to 600 mesh and after electropolishing, from which it can be seen that the open circuit potential after sandpaper sanding was finally stabilized at about -0.171 V and after electropolishing was finally stabilized at about 0.015 V, i.e. the open circuit potential of the samples increased by 0.186 V after electropolishing. Figure 11(b) shows the electric polarization curves of the sample in 3.5% NaCl solution after sandpaper polishing to 600 mesh and after electropolishing, and the results were obtained by fitting the electrochemical workstation as shown in Table 4, and the comparison showed that the self-corrosion potential of the sample after electropolishing increased from -0.248 V to -0.054 V, an increase of 0.194 V, and the corrosion current density decreased from 2.819×10^{-6} A/cm^2 decreased to 1.843×10^{-7} A/cm^2, indicating that the corrosion resistance of the sample surface was improved after electropolishing. This trend may be due to the chemical and electrochemical reactions that occur on the metal surface of stainless steel after electropolishing by the electrolyte and current in the electrolyte, resulting in the elimination of microscopic surface undulations and a flatter and smoother surface with fewer surface defects. In addition after electropolishing the metal surface can generate a layer of passivation film with a more uniform chemical composition, this layer of

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passivation film has better physical and chemical stability, and could prevent the metal surface from further oxidation or corrosion, and could greatly improve the corrosion resistance of stainless steel.

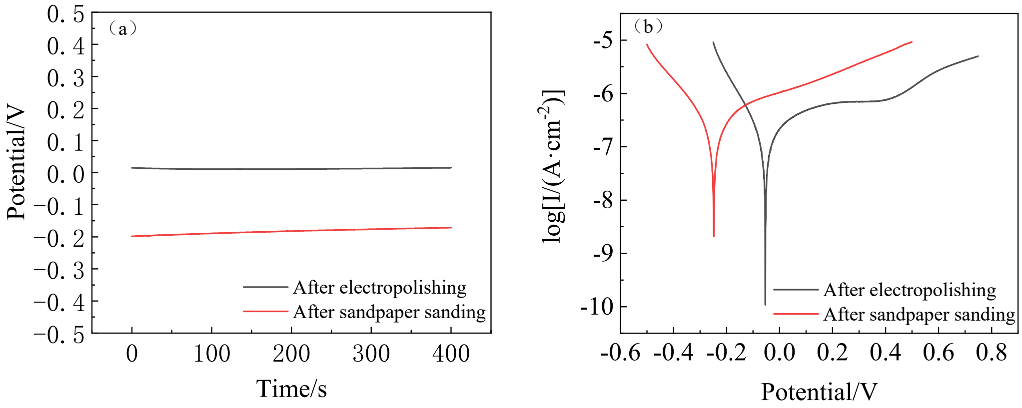

Figure 11. Electrochemical tests:(a) Open circuit potential;(b) Polarization curves

Table 4. Polarization curve fitting parameters

Samples	Corrosion potential/V	Corrosion current density/(A/cm^2)
After sandpaper sanding	-0.248	2.819×10^{-6}
After electropolishing	-0.054	1.843×10^{-7}

4. Conclusion

The following conclusions have been drawn from experiments with brush-type electrolytic polishing of SUS 304 stainless steel:

(1) Brush-type equipment can be used as an effective treatment for electrolytic polishing of the material, and diaphragm pump efficiency control of 20% can ensure that brush-type polishing is carried out effectively and can be applied to industrial production treatment of large pressure vessels that cannot be treated in ordinary electrolytic baths.

(2) The optimum process parameters for brush-type electrolytic polishing are current density 42 A/dm^2, electrolyte temperature 50 °C, and electrolytic polishing time 105 s.

(3)The influence of each process parameter on the difference in roughness Ra before and after electrolytic polishing is in the order of current density > electrolyte temperature > electrolytic polishing time.

(4) Under the appropriate process parameters electrolytic polishing can effectively improve the surface morphology of SUS 304 stainless steel material and reduce the surface roughness of the material, significantly improving its surface gloss, the final roughness of the specimen after electrolysis is only 0.064 μm, gloss is 549 GU, to mirror bright.

(5) Electrolytic polishing significantly enhanced the corrosion resistance of the SUS 304 stainless steel surface, its self-corrosion potential increased by 129 mV, and corrosion current density was reduced to 1.843×10^{-7} A/cm^2.

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