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Study on Ultrasound-assisted Brush Electrolytic Polishing Process for Nickel-based Alloys

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Abstract

In this study, the effects of ultrasonic power, polishing time, current density and electrolyte temperature on the ultrasonic-assisted brush electrolytic polishing effect of 690 nickel-based alloy were systematically investigated by one-way analysis using a concentrated phosphoric acid and concentrated sulfuric acid mixed system (4:1 by volume). The results showed that the surface condition of the 690 nickel-based alloy was significantly improved and its corrosion resistance was significantly enhanced after polishing under the conditions that the ultrasonic power was controlled at 60%, the electrolyte temperature was maintained at 40~45℃, the polishing time was set in the range of 60~100s, and the current density was adjusted to 50~60A/dm². The results provide an important theoretical basis and practical guidance for optimizing the electrolytic polishing process of 690 nickel-based alloy.

Keywords

Allloy 690; Electropolishing; Ultraphonic; Electro-brushing.

1. Introduction

Electrolytic polishing, as an efficient surface treatment technology, has a wide range of applications in the field of metal processing[1]. This technology removes the microscopic uneven part of the metal surface through electrochemical action, realizes the smoothing and brightening of the surface, and at the same time forms a dense passivation film, thus improving the corrosion resistance of the metal[2].690 nickel-based alloy, as an important engineering material, has a significant impact on the material's performance and service life due to its surface quality. Therefore, it is of great practical significance to study the electrolytic polishing process of 690 nickel-based alloy. In recent years, composite polishing methods, especially ultrasound-assisted electrolytic polishing technology, have received widespread attention for their high efficiency and environmental protection[3]. In this paper, ultrasonic energy is combined with electrolytic action, and by exploring the influence of different process parameters on the polishing effect, we aim to find the optimal process conditions for electrolytic polishing of 690 nickel-based alloy, and test and analyse its surface properties.

2. Experiment

2.1 Material Preparation and Pretreatment

The 690 nickel-based alloy sheet was selected as the research object for the experiment, and its chemical composition is shown in **Table 1**.After the material was laser cut to the specified size, it was sequentially sanded with different grits of sandpaper to remove surface impurities and oxidized layer. Subsequently, the surface was rinsed with deionized water and cleaned with ethanol and finally blown dry and set aside. The polished area was wrapped by PVC sample adhesive to ensure that the electrolytic polishing area was controlled at 0.5 dm^2. The polishing solution was a mixed system of concentrated phosphoric acid and concentrated sulfuric acid at a volume ratio of 4:1.

Table 1. Chemical composition of 690 nickel-based alloys

Element	Ni	Cr	Fe	Mn	Ti	C	Si	Al
Content/%	59.50	29.02	10.28	0.30	0.33	0.018	0.31	0.16

2.2 Experimental Setup and Process

The sketch of the experimental setup is shown in **Fig. 1**, which mainly includes cathode polishing brush, electrolyte storage tank, acid-resistant diaphragm pump, heater, working tank, power control cabinet and ultrasonic generator and other components. During the experiment, the ultrasonic power, polishing time, current density and electrolyte temperature were adjusted to investigate their effects on the ultrasonic-assisted brush electrolytic polishing of 690 nickel-based alloy. After the polishing was completed, the specimens were tested for surface properties and microscopic morphology observation.

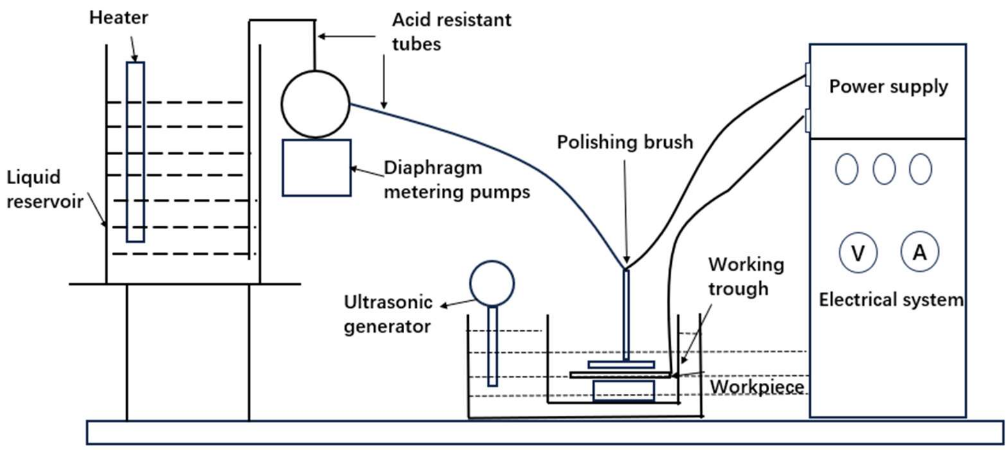

Fig. 1 Schematic diagram of brush polishing device

2.3 Performance Test

The surface roughness of the polished specimen was tested and analyzed by means of surface roughness measuring instrument, high magnification electron microscope and electrochemical workstation for surface roughness, micro-morphology and corrosion resistance. At the same time, field emission scanning electron microscope was utilized to further observe the microstructural changes on the specimen surface.

3. Results and Discussion

3.1 Effect of Process Parameters on Polishing Quality

3.1.1 Effect of ultrasonic power on polishing quality

Under the conditions of constant electrolyte temperature of 40°C, fixed polishing time of 80 seconds, and current density setting of 55A/dm^2, we deeply explored the influence of different ultrasonic power on the surface roughness of the specimen. As shown in **Fig. 2**. The experimental results show that with the gradual increase of ultrasonic power, the surface roughness of the specimen shows a trend of decreasing and then increasing. In particular, when the ultrasonic power reaches 60%, the roughness difference reaches its peak value. Further observation of the micro-morphological changes of the specimen surface in **Fig. 3** reveals that the scratches on the specimen surface are incompletely removed when the ultrasonic power is low; while the polishing effect is best in the ultrasonic power range of 60% to 70%, and the scratches are effectively removed. However, too high ultrasonic power

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leads to the phenomenon of overcorrosion pits on the surface of the specimen, which coincides with the roughness test results. This phenomenon can be attributed to the cavitation effect of ultrasound[4]: with the increase of ultrasonic power, the cavitation effect is enhanced, which helps to remove the passivation layer on the surface; however, too high ultrasonic power will lead to intense vibration of the polishing solution, destabilizing the gas layer and triggering the overcorrosion. Therefore, in ultrasound-assisted electrolytic polishing, the ultrasonic power should be controlled at about 60% to optimize the polishing effect.

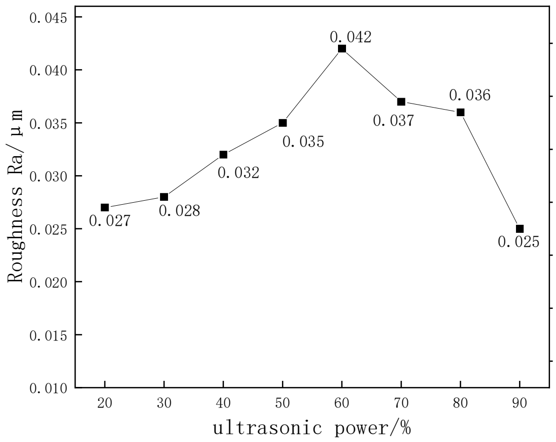

Fig. 2 Variation of roughness difference with ultrasonic power

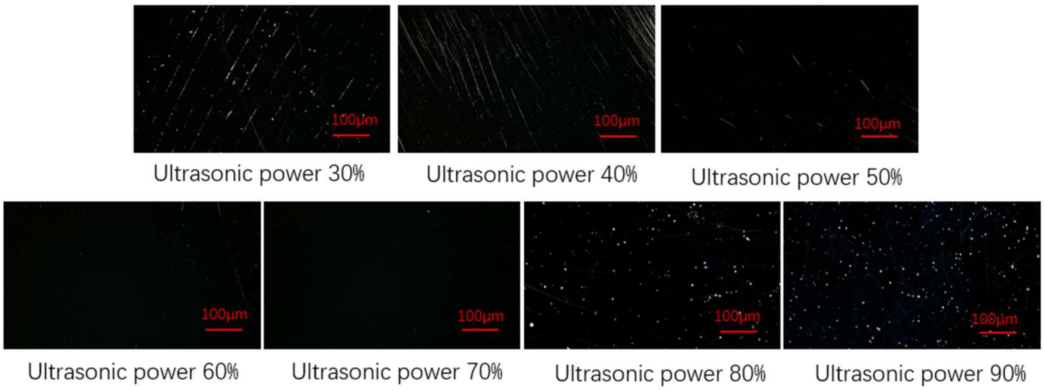

Fig. 3 Variation of surface morphology with ultrasonic power

3.1.2 The Effect of Electrolyte Temperature on Polishing Quality

Under the conditions of ultrasonic power of 60%, polishing time of 80s, and current density of $55A/dm^2$, the effect of electrolyte temperature on the polishing effect of brushes was investigated. As can be seen in **Fig. 4**, with the increase of electrolyte temperature, the roughness difference firstly increased, remained stable in the range of electrolyte temperature of 35~45℃, and then gradually decreased. **Fig. 5** shows that the better surface morphology can be obtained by polishing only when the electrolyte temperature is 40~45℃. This is because at low temperatures, metal ions diffuse slowly and have low solubility, leading to a decrease in current density[5]; while at high temperatures, the electrolyte viscosity decreases and the supply is fresh[6], so the electrolytic polishing is active, but too high a temperature may lead to overcorrosion. Taken together, the optimum electrolyte temperature range is 40~45℃.

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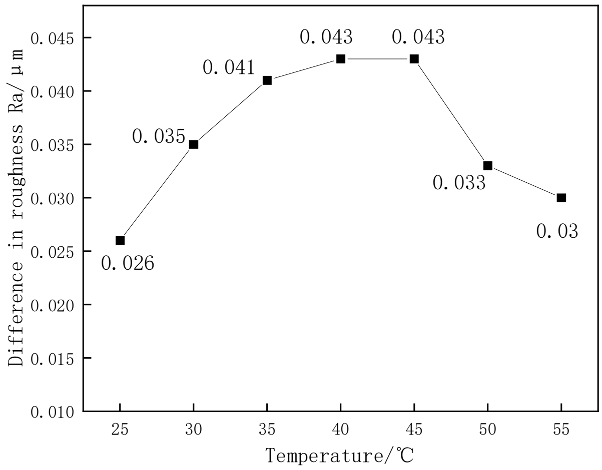

Fig. 4 Variation of roughness difference with electrolyte temperature

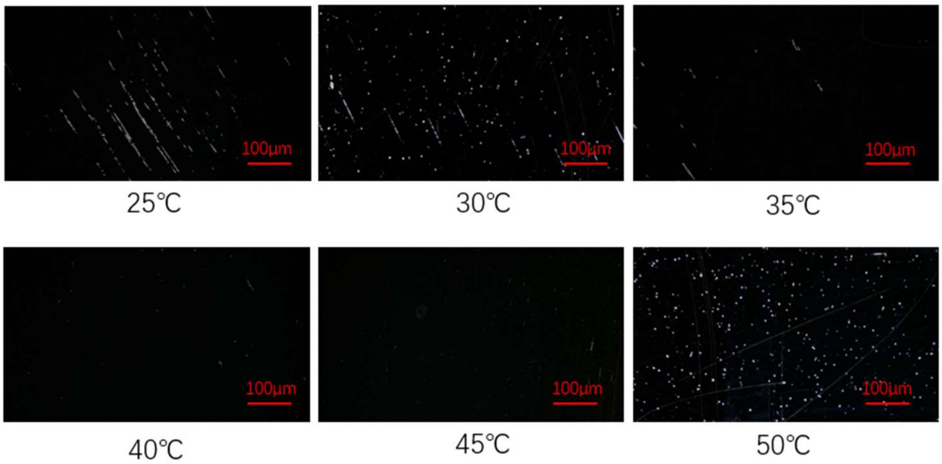

Fig. 5 Variation of surface morphology with electrolyte temperature

3.1.3 Effect of Polishing Time on Polishing Quality

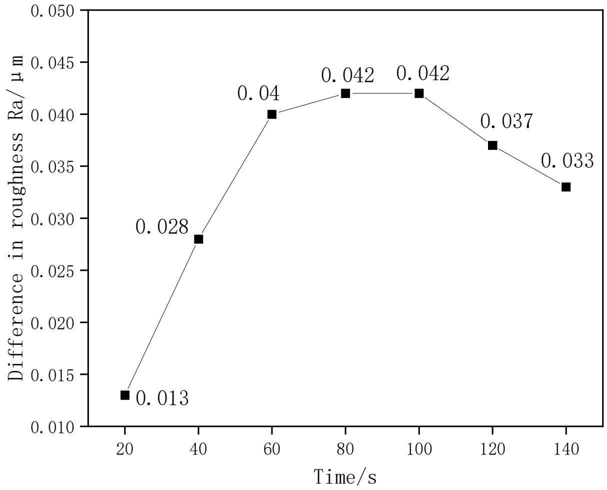

Fig. 6 Variation of roughness difference with polishing time

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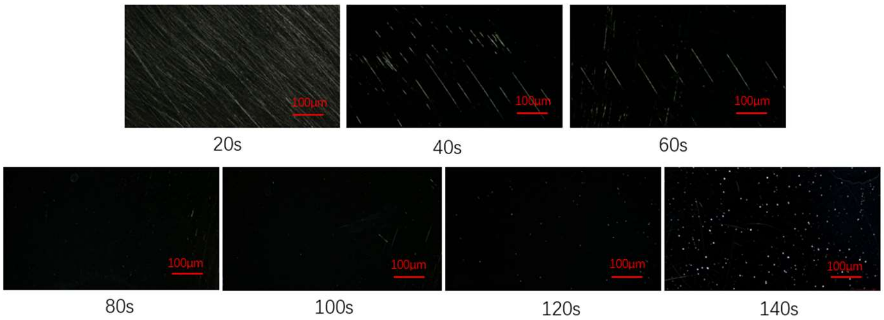

Fig. 7 Variation of surface morphology with polishing time

Under the condition of ultrasonic power of 60%, electrolyte temperature of 40°C, and current density of 55A/dm^2, we investigated the effect of polishing time on polishing quality. As shown in **Fig. 6**, with the increase of polishing time, the roughness difference value firstly increases rapidly and reaches the peak value at 60~100 seconds, and then decreases slowly. Combined with **Fig. 7**, it can be seen that the surface morphology of the specimen is best when the polishing time is between 60s~100s. When the polishing time is short, the electrolytic polishing process is not fully carried out, and the microscopic protrusion and depression height difference on the material surface is still in the process of decreasing, and with the increase of time, the electro-polishing process continues, and the material surface begins to flatten. However, too long a time will lead to etching pits on the metal surface and a decrease in surface quality. In summary, the optimum polishing time range is between 60s and 100s.

3.1.4 Effect of Current Density on Polishing Quality

Under the conditions of ultrasonic power of 60%, electrolyte temperature of 40°C and polishing time of 80s, the effect of current density on the effect of brush polishing was explored. As shown in **Fig. 8**, with the increase of current density, the surface roughness difference first increases and then decreases. When the current density is 50~60 A/dm^2, the surface roughness difference reaches the maximum and the surface morphology is optimal. This is because the increase of current density can improve the speed and efficiency of electrolytic polishing, but too high current density may lead to surface overcorrosion. Therefore, choosing the appropriate current density is equally important to obtain good polishing results. Combined with the observation of the surface morphology in **Fig. 9**, the surface scratches were completely removed when the current density was 50-60 A/dm^2 and no obvious overcorrosion pits appeared. Therefore, the optimum current density range is 50~60A/dm^2, which is the optimum current density for polishing.

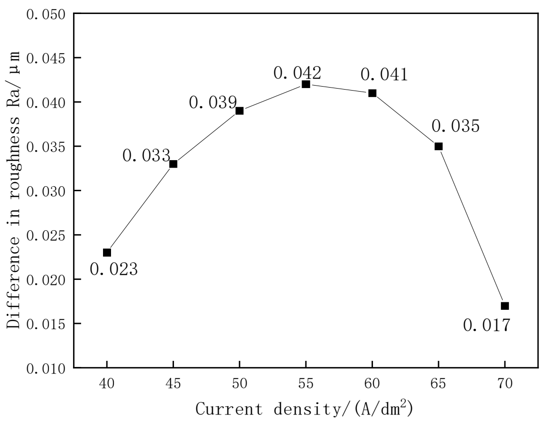

Fig. 8 Variation of roughness difference with current density

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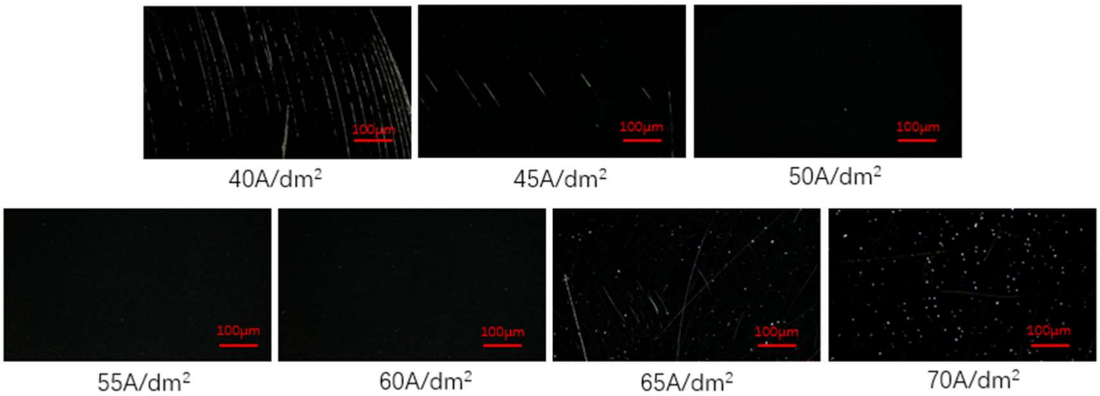

Fig. 9 Variation of surface morphology with current density

In summary, in the ultrasound-assisted electrolytic polishing process, the selection of process parameters has a significant effect on the polishing quality. The best polishing effect can be obtained under the conditions of 60% ultrasonic power, 55±5A/dm^2 current density, 120±20s polishing time, and electrolyte temperature of 40~45°C.

3.2 Surface Performance Test after Polishing

3.2.1 Corrosion Resistance Test before and after Polishing under Optimum Process Conditions

Fig. 10 shows the kinetic potential polarisation curves of 690 nickel-based alloy after sandpaper polishing and the alloy after electrolytic polishing under the optimum process parameters in a solution with a mass fraction of 3.5% NaCl. By comparing these two curves and combining them with the corrosion parameters obtained by fitting in **Table 2**. The enhancement of the corrosion resistance of the alloy by electrolytic polishing can be clearly observed. Specifically, after electrolytic polishing, the self-corrosion potential of the alloy was significantly increased from -0.791 V to -0.135 V. Meanwhile, the self-corrosion current density was drastically reduced from 3.359×10-5 A/cm^2 to 1.42×10-6 A/cm^2 This improvement is mainly attributed to the formation of a stable and dense passivation film on the surface of the alloy during the electrolytic polishing process[7]. This film is not only smooth and even, but also effectively eliminates surface defects such as corrosion pits, which significantly enhances the alloy's corrosion resistance. This discovery is important for improving the service life and reliability of 690 nickel-based alloy in corrosive environments.

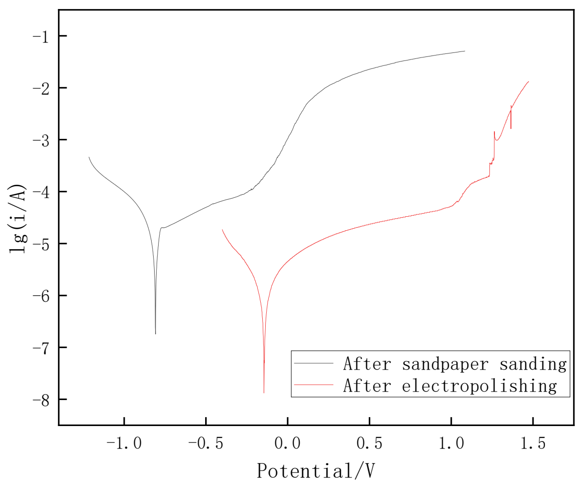

Fig. 10 Polarization curves

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Table 2. Polarization curve fitting parameters

Samples	Corrosion potention/V	Corrosion current density/(A/cm^2)
After sandpaper sanding	-0.791	3.359×10^{-5}
After electropolishing	-0.135	1.42×10^{-6}

3.2.2 Comparison between 690 Nickel-based Alloy after Polishing and the Substrate before Polishing under Optimum Process Conditions

As can be seen from Fig. **11**, the surface quality of 690 nickel-based alloy was significantly improved after electrolytic polishing under the optimum process conditions. Compared with the pre-polished surface, the surface of the alloy after polishing shows a mirror-like luster, and the characteristic of reflected light changes from diffuse reflection to specular reflection, which significantly enhances the visual effect and finish of the surface. In addition, the surface of the polished alloy was able to reflect text clearly, further demonstrating the significant improvement in surface quality. By comparing the microscopic surface morphology of the sandpapered and electrolytically polished alloys as shown in Fig. **12**, it can be clearly seen that defects such as scratches and damaged layers have been effectively removed from the polished alloys, and replaced by a smooth, flat and perfect surface condition. This change not only enhances the aesthetics of the alloy, but more importantly, lays a solid foundation for its performance in subsequent applications.

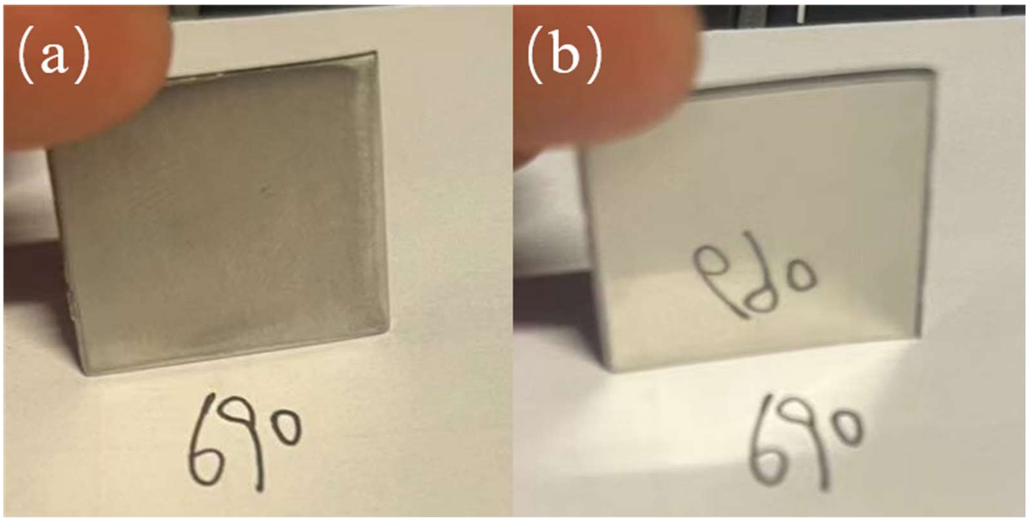

Fig. 11 Macroscopic comparison between the substrate before polishing and the sample polished under optimal process conditions (a) Before polishing (b) After polishing

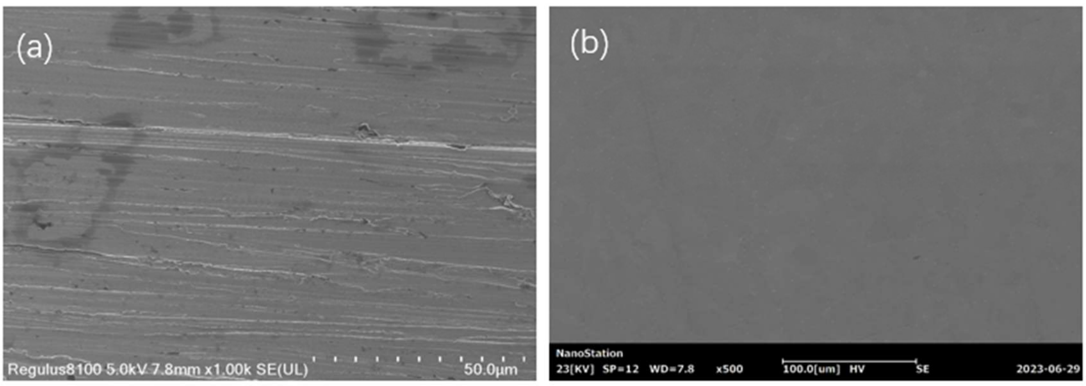

Fig. 12 SEM images of sample: (a) polished surface; (b) electropolished surface

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4. Conclusion

After an in-depth investigation of the implementation of ultrasound-assisted brush electrolytic polishing experiments on 690 nickel-based alloys, the following important conclusions are drawn in this paper:

(1) In the process of electrolytic polishing, the optimisation of process parameters is crucial for obtaining ideal polishing results. The experimental results show that the best polishing effect is achieved when the ultrasonic power is controlled at 60%, the electrolyte temperature is maintained at 40~45°C, the polishing time is limited to 60~100 seconds, and the current density is set at 50~60 A/dm^2. Under this parameter combination, the surface roughness difference of the specimen reaches the maximum, the surface shows smooth and flat characteristics, and defects such as scratches and corrosion pits are effectively removed, thus achieving a perfect surface condition.

(2) Electrolytic polishing not only significantly improves the surface quality of 690 nickel-based alloy, but also positively affects its corrosion resistance. The experimental data show that the self-corrosion potential of the electrolytically polished specimen is significantly increased from -0.791V to -0.135V, while the self-corrosion current density is also greatly reduced from 3.359×10-5 A/cm^2 to 1.42×10-6 A/cm^2. This change shows that the electrolytic polishing effectively enhances the corrosion resistance of the alloy, which provides a strong guarantee for the long-term stable operation of the alloy in a corrosive environment. stable operation in the corrosive environment.

In conclusion, the optimisation of the electrolytic polishing process parameters in this study has successfully improved the surface quality and corrosion resistance of 690 nickel-based alloy. This achievement not only enriches the theoretical system of electrolytic polishing technology, but also provides important technical support and practical guidance for the application of nickel-based alloy in high-end manufacturing industry.

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