J. Cent. South Univ. (2015) 22: 422−429
DOI: 10.1007/s11771-015-2538-2

Springer

Effect of electromagnetic and ultrasonic cast rolling on microstructure and properties of 1050 aluminum substrate for presensitized plate

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Abstract: The 1050 aluminum alloy strip was prepared by means of electromagnetic and ultrasonic cast rolling on the modified asymmetric twin roll caster, and then the aluminum substrate for presensitized plate was prepared through cold rolling and annealing. The effects of electromagnetic and ultrasonic cast rolling on microstructure, mechanical properties, surface roughness and electrolytic corrosion properties of 1050 aluminum substrate were studied. The results show that electromagnetic and ultrasonic cast rolling can decrease the average crystallite size of aluminum substrate by 5 μm, increase the crystal boundaries with uniform distribution, and make the second-phase particles with smaller size distributed dispersively in the substrate, meanwhile, it can increase the tensile strength, elongation and micro-hardness by 4.58%, 9.85% and HV 2, respectively, reduce the surface roughness, make the surface appearance more even, electrolytic corrosion polarization curve of aluminum substrate more smooth and the surface corrosion pits with regular shape more dispersive.

Key words: 1050 aluminum alloy; electromagnetic and ultrasonic cast rolling; microstructure; mechanical properties; electrolytic corrosion property

1 Introduction

As the most important printing plate nowadays, presensitized plate has the largest consumption [1], and it generally uses aluminum alloy as the material of substrate. The quality of aluminum substrate has a great effect on the resolution, press life and sensitivity of presensitized plate, so the requirements for chemical component, mechanical property, surface roughness and electrolytic corrosion property of aluminum substrate are rigorous [2−4]. Researchers now have done lots of work on the advanced and reasonable technology to prepare the aluminum substrate with high quality.

VAN ALPHEN et al [5] found that the presensitized plate substrate that has small grains and high content of uniform trace elements could obtain better electrolytic corrosion property. LI et al [6] indicated that increasing cold rolling reduction before annealing of aluminum substrate could prompt precipitated phase to precipitate dispersively and increase the dislocation density, thereby improving the electrolytic corrosion property. LI et al [7] compared the intermediately annealed 1052 aluminum substrate with the unannealed sample, and discovered that the intermediately annealed substrate had smaller grains, more precipitated-phases, and higher electrolytic corrosion property. YANG [8] showed that electromagnetic field could enhance the surface uniformity of aluminum substrate and make precipitated-phases distribute evenly, thus improving the uniformity of etch pits.

Researchers also have done lots of work on the application of electromagnetic field or ultrasonic wave in aluminum alloy casting or cast rolling in recent years [9−15], and it is found that electromagnetic field or ultrasonic wave could refine crystals during the liquid forming process of aluminum alloy, and then improve the properties of aluminum alloy strips. However, it is a new technology to apply electromagnetic and ultrasonic composite energy field in aluminum alloy cast rolling, which has been less reported so far.

In this work, 1050 aluminum alloy strip was prepared by means of electromagnetic and ultrasonic cast rolling on the modified asymmetric twin roll caster, and then the aluminum substrate for presensitized plate was prepared by cold rolling and annealing the aluminum alloy strip. The effects of electromagnetic and ultrasonic cast rolling on the microstructure, mechanical properties,

Foundation item: Project(2014CB046702) supported by the National Basic Research Program of China; Project supported by the Postdoctoral Science Foundation of Central South University, China
Received date: 2013−11−04; **Accepted date:** 2014−03−14
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surface roughness and electrolytic corrosion properties of 1050 aluminum substrate were investigated to obtain an energy-saving preparation method of aluminum substrate for presensitized plate.

2 Experimental

2.1 Materials

1050 aluminum alloy was used to prepare aluminum substrate for presensitized plate, and the chemical composition is listed in Table 1.

Table 1 Chemical composition of 1050 aluminum alloy (mass fraction,%)

Si	Fe	Cu	Mn	Mg	Zn	Ti	Al
0.25	0.40	0.05	0.05	0.05	0.05	0.03	Bal.

Firstly, the aluminum strips for aluminum substrate was prepared by means of electromagnetic and ultrasonic cast rolling. Horizontal twin roll caster (Fig. 1) was modified to carry out electromagnetic and ultrasonic cast rolling, where the upper and lower plates of casting mouth were fixed asymmetrically, thereinto, the upper plate was short and did not contact the roller, which was conducive to importing ultrasonic energy field and

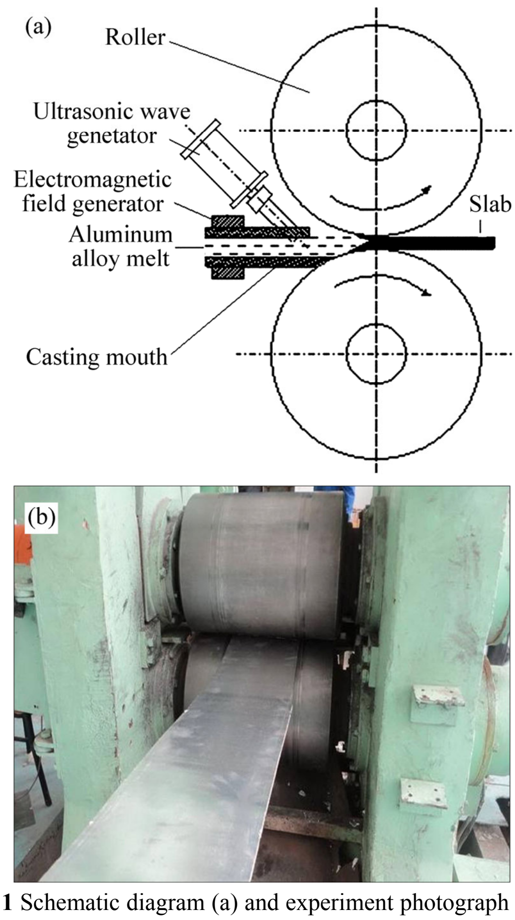

Fig. 1 Schematic diagram (a) and experiment photograph (b) of electromagnetic and ultrasonic cast rolling

releasing the heat and hydrogen of aluminum melt. Meanwhile, the central plane of casting mouth was lower than that of cast-rolled strip, and the contact area of aluminum melt and bottom roller was increased by 400 mm^2, which enhanced the heat convection between aluminum melt and bottom roller. Experiments show that the speed of asymmetric cast rolling could be increased to 1.2−1.4 m/min, thereby the productivity of cast rolling could be improved remarkably.

Through series of experiments, the cast-rolled strip with thickness of 5.8 mm and width of 200 mm was prepared through importing electromagnetic and ultrasonic composite energy field to asymmetric cast rolling, where the center frequency of electromagnetic field was (13±1) Hz, exciting current was 10 A, ultrasonic output power was 200 W, and ultrasonic frequency was (20±0.2) kHz.

Then, the aluminum substrate for presensitized plate with thickness of 0.27 mm was prepared through homogenizing annealing, the first time cold rolling, intermediate annealing and the second time cold rolling, where the thicknesses of aluminum substrate in each pass during the first time cold rolling were 5.8, 4.3, 3.3, 2.5, 1.8, 1.4, 1.2, and 1.08 mm, respectively. The intermediate annealing temperature and time were 380 °C and 2 h, and the thicknesses of aluminum substrate in each pass during the second time cold rolling were 1.08, 0.88, 0.68, 0.48, and 0.27 mm, respectively.

The aluminum substrates with thickness of 0.27 mm prepared by traditional cast rolling and hot rolling were also analyzed to compare with the electromagnetic and ultrasonic cast rolled substrate.

2.2 Test methods

Metallographic structures of aluminum substrate samples were recorded by DMI-5000M metallographic microscope. The surfaces were electrolytic polished and anodized, and the distributions of second-phase particles were observed on scanning electron microscope. Tensile properties of aluminum substrates were tested on WPL-300 universal testing machine. The micro-hardness of aluminum substrates was measured with HV-1000 Vickers hardness tester. Surface roughness and surface appearance of aluminum substrates were recorded on Veeco Wyko NT9100 optical profiler. Electrolytic corrosion polarization curves of aluminum substrates were obtained on IM6ex (ZAHNER elecktrik) electrochemical equipment. And the sample size was 10 mm ×10 mm, the concentration of HCl aqueous solution was 2.5% (volume fraction), reference electrode was standard calomel electrode, auxiliary electrode was Pt electrode, and scanning speed was 1 mV/s. Surface appearances of the aluminum substrates electrolytically etched were observed on scanning electron microscope.

3 Results and discussion

3.1 Microstructure of cast-rolled strip

Figure 2 shows the metallographic structures of aluminum strips prepared by traditional cast rolling and electromagnetic and ultrasonic cast rolling. It is found that the traditional cast rolled strip has big, uneven crystal grains and developed dendrites. Its crystal boundaries are shaped as long strip and crystal grain size is between 50 and 55 μm. But the electromagnetic and ultrasonic cast rolled strip has small and uniform crystal grains, the grain boundary is regular, the grain boundaries shaped as long strip are not observed, and the

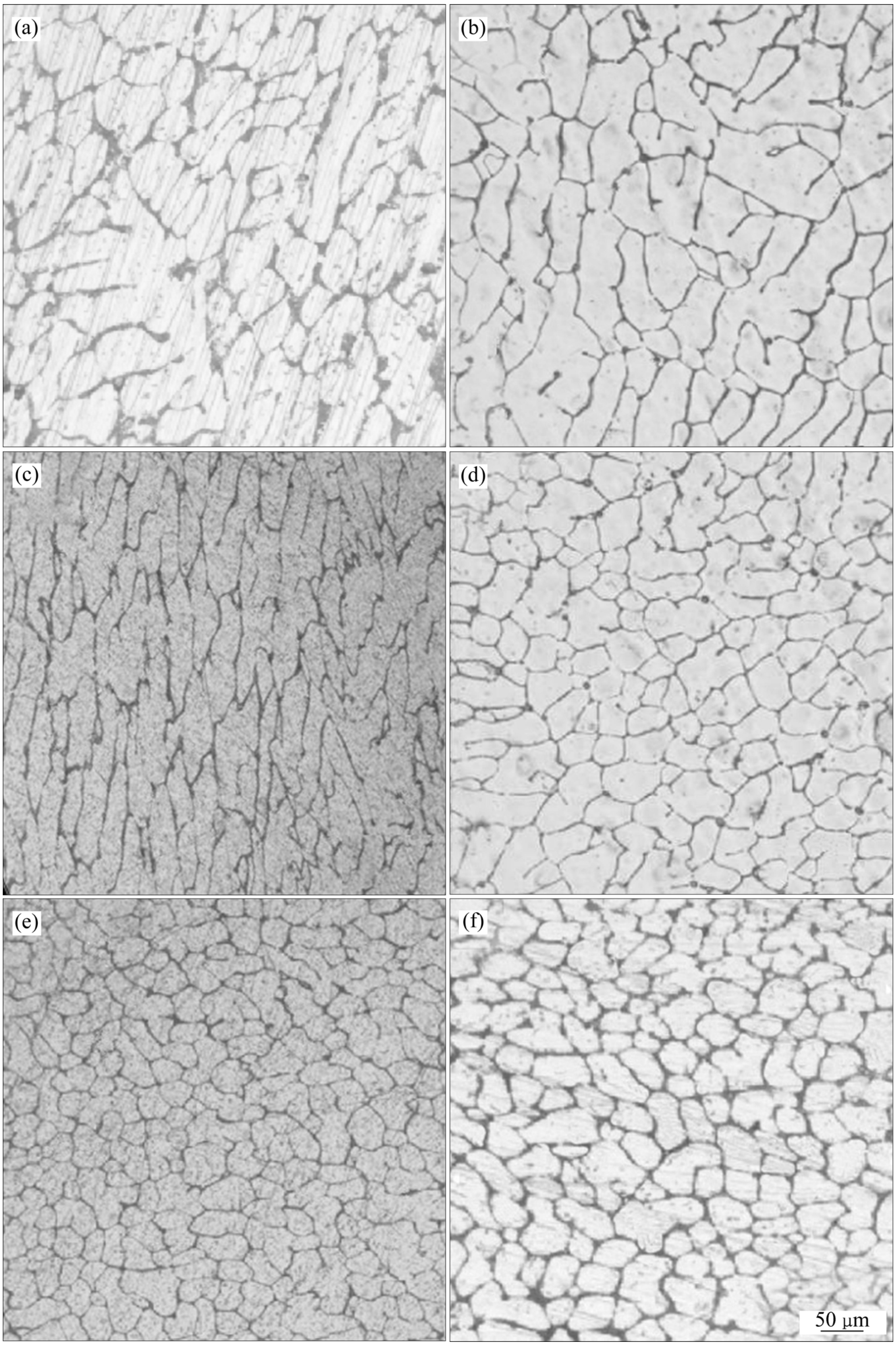

Fig. 2 Metallographic structure of aluminum cast-rolled strips prepared by different processes: (a) Normal plane, traditional cast rolling; (b) Cross section, traditional cast rolling; (c) Longitudinal section, traditional cast rolling; (d) Normal plane, electromagnetic and ultrasonic cast rolling; (e) Cross section, electromagnetic and ultrasonic cast rolling; (f) Longitudinal section, electromagnetic and ultrasonic cast rolling

crystal grain size is between 30 and 35 μm. The reasons of generating the fine grain structure are the effects of electromagnetic and ultrasonic coupled energy field: the Lorentz force generated by electromagnetic field and the shock wave generated by ultrasonic wave cavitation phenomenon oscillate and stir the aluminum melt, and thus break the growing dendrites and columnar crystals and form a large number of new crystal nuclei dispersing in the metastable melt, thereby the fine isometric crystals are obtained. Meanwhile, the oscillating and stirring effects of electromagnetic and ultrasonic composite energy field make the aluminum melt more uniform, and thus reduce the composition segregation effectively.

3.2 Microstructure of aluminum substrate

Figure 3 shows the metallographic structures of aluminum substrates. As illustrated, traditional cast rolled substrate has typical cold rolled grain structure: the crystal boundaries are not obvious and stretched along the rolling direction, crystal gains are distributed unevenly and the grain size is about 26 μm. In contrast, the microstructure of electromagnetic and ultrasonic cast rolled substrate has fibrous grain structure: the crystal boundaries are observed obviously and the grain size is only about 21 μm. The crystal boundaries with uniform distribution increase, and the uniformity of crystal boundary is better than that of traditional cast rolled substrate and comparable to hot rolled substrate. These are due to the electromagnetic and ultrasonic coupled energy field turning long dendrites of cast rolled strip into fine isometric crystals, which results in the small crystal grains and the uniform crystal boundaries after cold rolling and annealing.

The distributions of second-phase particles on aluminum substrates through scanning electron microscope are shown in Fig. 4. It can be seen that the second-phase particles of traditional cast rolled substrate are distributed unevenly, the quantity is less and average size is larger. But there are more second-phase particles with smaller size in the electromagnetic and ultrasonic cast rolled substrate and hot rolled substrate, which are distributed dispersively in the substrate. The oscillating and stirring effects of electromagnetic and ultrasonic composite energy field make the solute accumulation on solidification front thinned or disappeared. Second phase particles precipitate evenly, the uniform diffusion of the solute is accelerated and anisotropic growth of the second phase is restrained, which turns second phase particles into spherical particles distributed evenly in the cast rolled strip.

3.3 Mechanical properties of aluminum substrate

Tensile properties of aluminum substrates prepared by different processes are given in Table 2, and it can be seen that compared with the traditional cast rolled substrate, the tensile strength and elongation of electromagnetic and ultrasonic cast rolled aluminum substrate are increased by 4.58% and 9.85%, respectively, and are comparable to those of the hot rolled substrate.

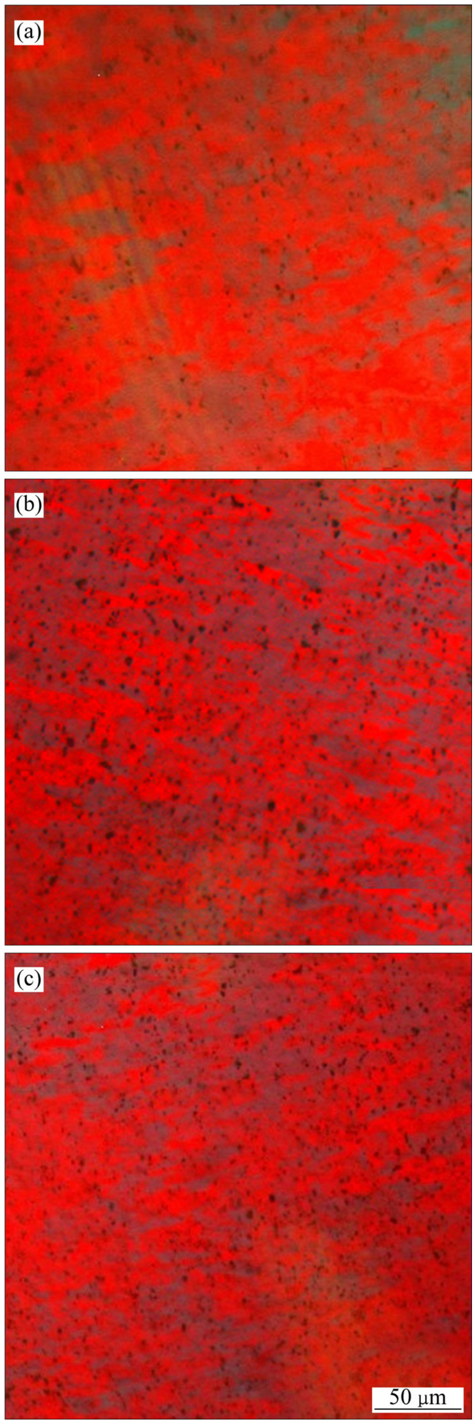

Fig. 3 Metallographic structures of aluminum substrates prepared by different processes: (a) Traditional cast rolling; (b) Electromagnetic and ultrasonic cast rolling; (c) Hot rolling

As the supporting body of presensitized plate, the heated aluminum substrate must still have good mechanical properties. Table 3 lists the tensile properties

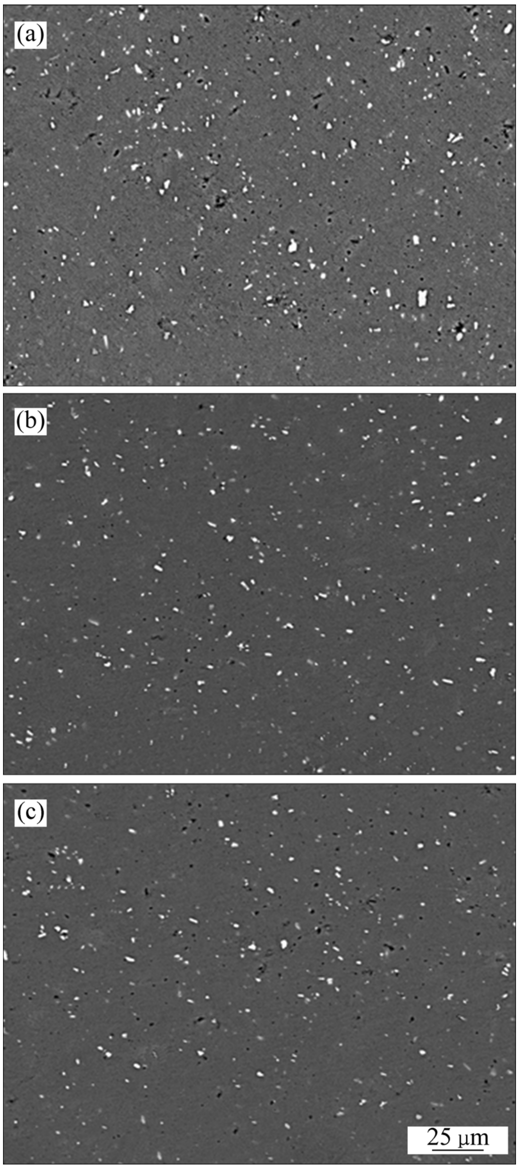

Fig. 4 Distribution of second-phase particles on aluminum substrates prepared by different processes: (a) Traditional cast rolling; (b) Electromagnetic and ultrasonic cast rolling; (c) Hot rolling

Table 2 Tensile properties of aluminum substrates prepared by different processes

Process	Tensile strength/MPa	Elongation/%
Traditional cast rolling	174.10	2.03
Electromagnetic and ultrasonic cast rolling	182.08	2.23
Hot rolling	181.45	2.38

of the aluminum substrates heated at 240 °C and 260 °C, and it is shown that the tensile properties of electromagnetic and ultrasonic cast rolled substrate are similar with those of the hot rolled substrate. The tensile strength and elongation are respectively 153−155 MPa and 3.8%−4.0%, but the tensile strength of traditional rolled substrate is only about 148 MPa.

Table 3 Tensile properties of aluminum substrates prepared by different processes after heating

Process	Tensile strength/MPa	Elongation/%	Heating condition
Traditional cast rolling	147.15	3.24	240 °C, 10 min
Electromagnetic and ultrasonic cast rolling	153.23	3.89	
Hot rolling	154.35	4.05	
Traditional cast rolling	148.53	3.41	260 °C, 4 min
Electromagnetic and ultrasonic cast rolling	154.14	3.94	
Hot rolling	154.05	3.98	

Table 4 shows the micro-hardness of aluminum substrates prepared by different processes. It is observed that the micro-hardness of electromagnetic and ultrasonic cast rolled substrate is higher than that of traditional cast rolled substrate by HV 2, and is comparable to that of the hot rolled substrate.

Table 4 Micro-hardness of aluminum substrates prepared by different processes

Measuring position	Traditional cast rolling	Electromagnetic and ultrasonic cast rolling	Hot rolling
1	50.4	52.1	51.5
2	50.6	52.9	51.3
3	50.7	52.4	51.0
4	50.1	51.8	51.7
5	51.0	52.3	51.9
Average value	50.29	52.30	51.48

In summary, electromagnetic and ultrasonic cast rolling improves the tensile strength, elongation and micro-hardness of aluminum substrate, and makes it meet the requirements of printing for the mechanical properties of presensitized plate. This is because electromagnetic and ultrasonic coupled energy field refines the crystal grains of cast-rolled strip, and the refined crystal grains have fine crystal strengthening effect during the processes of intermediate annealing and cold rolling.

3.4 Surface roughness of aluminum substrate

Low surface roughness and uniform surface appearance are the prerequisites to get good presensitized plate pits, so the surface roughness and surface appearance of aluminum substrate were tested, as shown in Table 5 and Fig. 5, respectively.

Table 5 shows that the R_a value of electromagnetic and ultrasonic cast rolled substrate is lower than that of traditional cast rolled substrate, but the R_a value and S_m value are slightly higher than those of the hot rolled

Table 5 Surface roughness of aluminum substrates prepared by different processes

Process	R_a/μm	R_z/μm	S_m/μm
Traditional cast rolling	0.305	1.125	2.80
Electromagnetic and ultrasonic cast rolling	0.253	1.115	2.69
Hot rolling	0.212	1.102	2.11

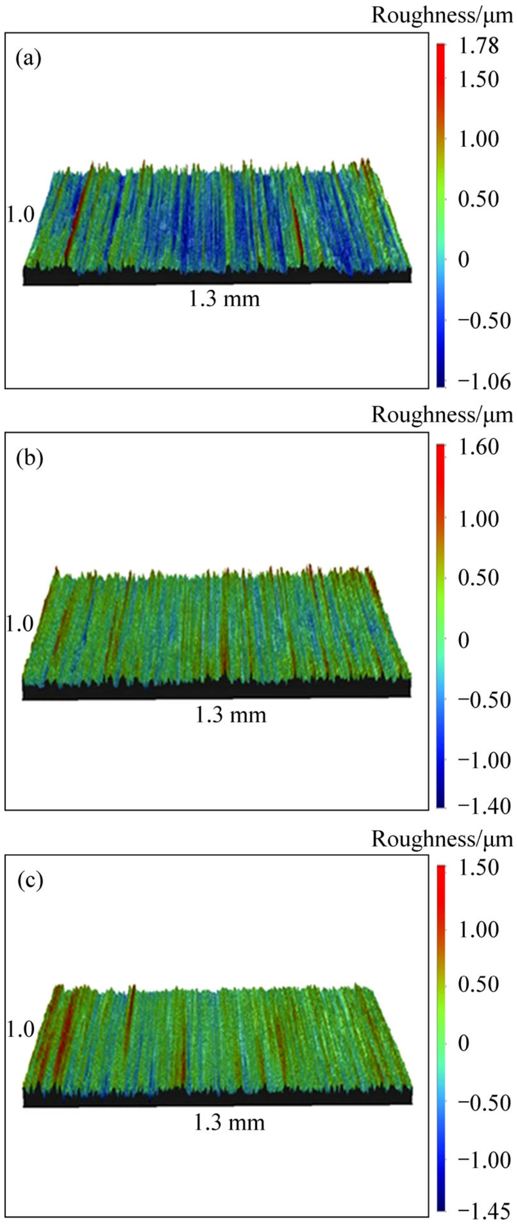

Fig. 5 Surface appearance of aluminum substrates prepared by different processes: (a) Traditional cast rolling; (b) Electromagnetic and ultrasonic cast rolling; (c) Hot rolling

substrate, because the cold rolling roller used here does not meet the enterprise standard.

Figure 5 illustrates that surface uniformity of electromagnetic and ultrasonic cast rolled substrate is better than that of traditional cast rolled substrate obviously and is comparable to that of hot rolled substrate, which is resulted from the microstructure difference of cast rolled strips. The uneven microstructure and serious segregation of traditional cast rolled strip result in the inhomogeneous deformation of crystal grain during cold rolling, and cause fragile intergranular fracture when the strip bears uniaxial tensile stress, thus leading to the inferior surface uniformity ultimately. In contrast, electromagnetic and ultrasonic cast rolled strip has fine isometric crystals and its segregation is reduced remarkably, which increases the coordination of inhomogeneous deformation, and thus improves the surface uniformity of aluminum substrate, which is conducive to forming uniform electrolytic pits.

3.5 Electrolytic corrosion property of aluminum substrate

Figure 6 shows the electrolytic corrosion polarization curves of aluminum substrates by different processes, and the contrastive analysis shows that the polarization curve of electromagnetic and ultrasonic cast rolled substrate is smooth and does not have obvious burr and fluctuation, which is better than that of hot rolled substrate, but there is obvious fluctuation in the polarization curve of traditional cast rolled substrate, and the polarization curve's smoothness is inferior. All of these indicate that the electrolytic corrosion uniformity of electromagnetic and ultrasonic cast rolled substrate or hot rolled substrate is better than that of traditional cast rolled substrate.

Figure 7 shows the surface corrosion morphologies of aluminum substrates. As shown, corrosion pits appear on surfaces of the aluminum substrates electrolytically etched in HCl aqueous solution. Thereinto, traditional cast rolled substrate has the worst corrosion morphology, where some areas are corroded incompletely, there is a large difference in the corrosion depth of different areas, the distribution uniformity of corrosion pits is inferior, and there are some long corrosion pits distributed unevenly along the rolling direction. However, electromagnetic and ultrasonic cast rolled substrate has better corrosion morphology, where the corrosion pits with regular shape are distributed dispersively and most of them are fine square pits. And moreover, the EDS energy spectrum analysis (Fig. 8) shows that the surface composition of corroded aluminum substrate is aluminum, which indicates that the second phase particles are corroded completely. This is because electrochemical corrosion generally generates in crystal defect and extends along the crystal defect. Crystal boundary and the second phase are the preferential corrosion areas. Electromagnetic and ultrasonic cast rolled substrate has fine, uniform crystal boundaries and second phase particles, which results in the excellent electrolytic corrosion uniformity.

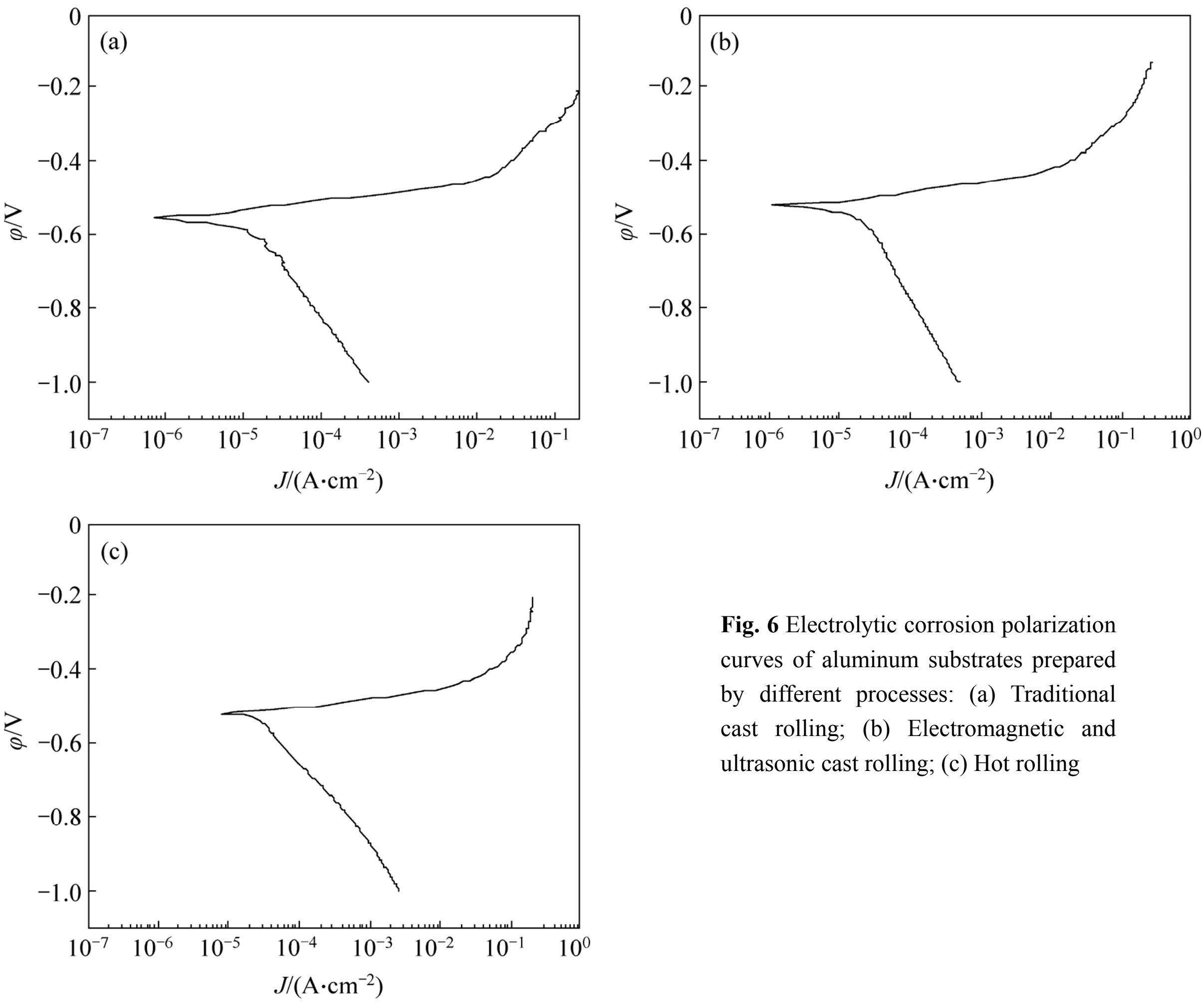

Fig. 6 Electrolytic corrosion polarization curves of aluminum substrates prepared by different processes: (a) Traditional cast rolling; (b) Electromagnetic and ultrasonic cast rolling; (c) Hot rolling

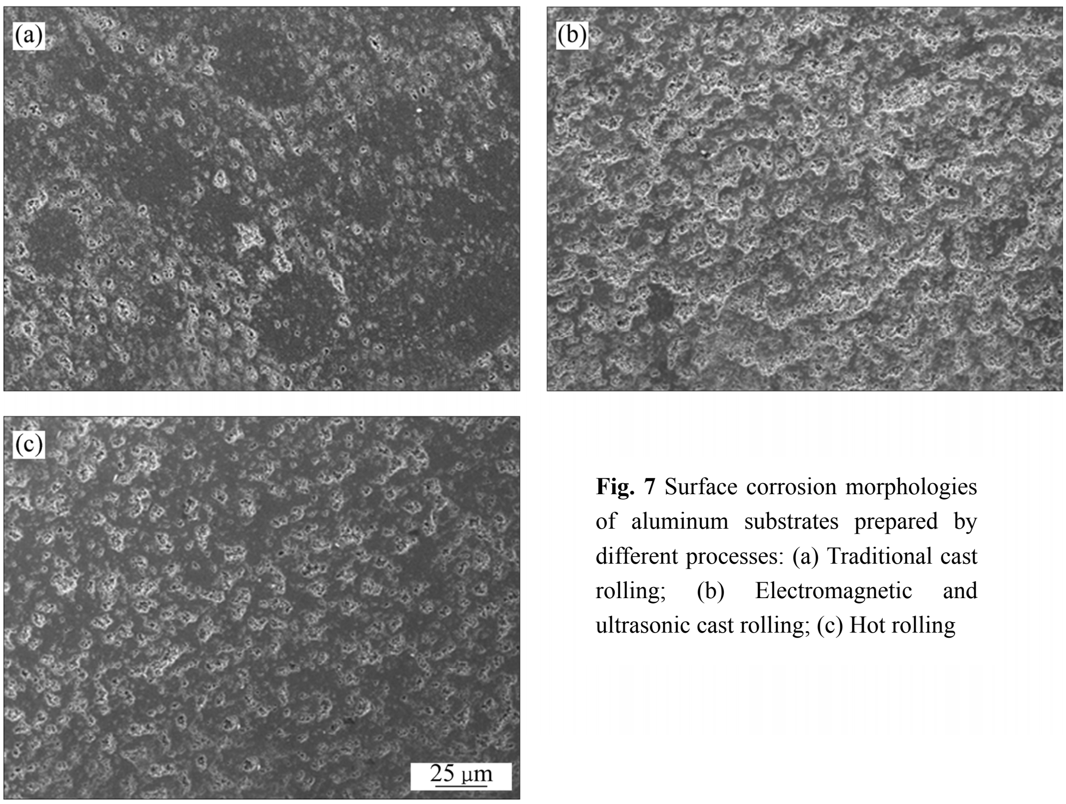

Fig. 7 Surface corrosion morphologies of aluminum substrates prepared by different processes: (a) Traditional cast rolling; (b) Electromagnetic and ultrasonic cast rolling; (c) Hot rolling

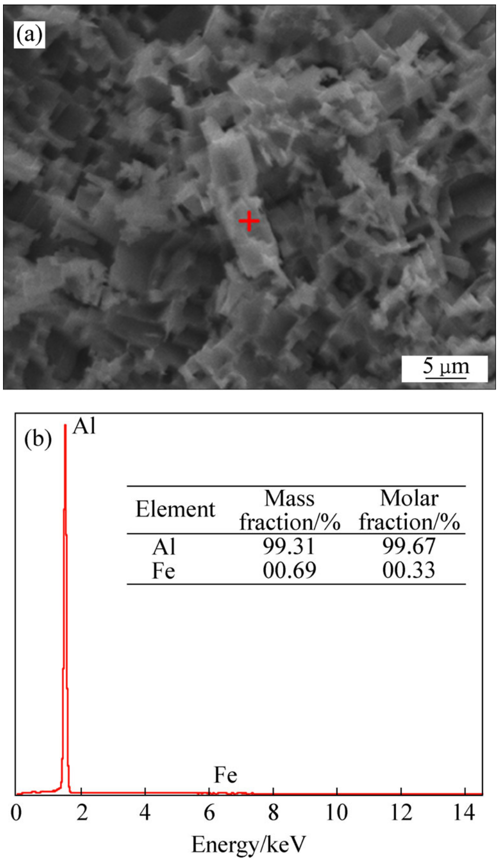

Fig. 8 TEM image (a) and surface EDS energy spectrum (b) of aluminum substrates prepared by electromagnetic and ultrasonic cast rolling after electrolytic corrosion

Consequently, electromagnetic and ultrasonic cast rolling improves the electrolytic corrosion properties of aluminum substrate and makes it meet the requirements of presensitized plate.

4 Conclusions

1) Compared with traditional cast rolled aluminum substrate, average grain size of electromagnetic and ultrasonic cast rolled aluminum substrate is decreased by 5 μm, the crystal boundary with uniform distribution increases, and the second-phase particles with smaller size are distributed dispersively in the substrate.

2) Compared with traditional cast rolled aluminum substrate, tensile strength, elongation and micro-hardness of electromagnetic and ultrasonic cast rolled aluminum substrate are increased by 4.58%, 9.85%, and HV 2, respectively. Moreover, electrolytic corrosion polarization curve of electromagnetic and ultrasonic cast rolled aluminum substrate is smoother, and its corrosion pits with regular shape are distributed dispersively.

3) Electromagnetic and ultrasonic cast rolling can make microstructure, mechanical properties and electrolytic corrosion properties of aluminum substrate meet the requirements of presensitized plate. However, the optimal match between electromagnetic and ultrasonic cast rolling and the subsequent processing still needs further research.

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(Edited by FANG Jing-hua)