Structural optimisation and electrochemical behaviour of AlCrN coatings

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Abstract

AlCrN coatings were deposited on 316L stainless steel by multi-arc ion plating. The phase structures were controlled and optimised by vacuum annealing at 700 °C, 800 °C, and 900 °C, each for 2 hours. The microstructures and morphologies of these coatings were examined by X-ray diffraction, X-ray photoelectron spectroscopy, and scanning electron microscope, in association with adhesion strength measurement, residual stress measurement and potentiodynamic polarisation with 3.5% NaCl and 10% H₂SO₄ solutions. Results show that the solid solution hcp-(Cr,Al)N phase of as-deposited AlCrN coatings decomposes into hcp-AlN and CrN phases, then further decompose into N and Cr with increasing annealing temperature. Metal particles and droplets on the coating surface were gradually removed simultaneously when compared with as-deposited coatings. The highest adhesion strength was obtained after annealing at 700 °C. It decreased with increasing annealing temperature due to the σ -FeCr phase and Cr₂N phases, and the residual stress decreasing. The potentiodynamic polarisation

measurements showed that the corrosion resistance of such coatings was significantly improved after annealing: the coatings annealed at 800 °C showed the best protective efficiency because some corrosion resistance phases (h-AlN, Al₂O₃, CrN, and Cr₂N) were generated.

Keywords: Multi-arc ion plating; AlCrN coatings; Vacuum annealing; Corrosion resistance

1Introduction

316L stainless steel (SS) has been extensively applied in the chemical and biomedical industries due to its excellent corrosion resistance [1-6]; however, low wear resistance and poor pitting corrosion resistance to chlorine ions have restricted its application in these engineering fields. Therefore, some approaches, such as plasma or gas nitriding [7-10] and physical vapour deposition (PVD) [11-14], could be employed to improve the surface hardness and pitting corrosion resistance of 316L SS. For CrN-based coating, PVD process was more effective to improve the corrosion resistance of 316L SS compared with plasma or gas nitriding processes [14,15].

Multi-arc ion plating (M-AIP) is a PVD process that has been widely used to produce a protective coating on the surface of SS due its higher ionisation rate, deposition rate, and lower deposition temperature [16]. It has been reported that CrN or TiN coatings with columnar growth deposited by M-AIP reveal better corrosion resistance against H₂SO₄ or NaCl solutions [17-19]. Nevertheless, some pores and pinholes forming on the surface of CrN or TiN coatings were observed, which would act as diffusion paths through which corrosive ions could accelerate the corrosion of such coatings, and further reduce their protective ability [14,20-21]. Recently, it has been reported that elemental Al has been added to form multi-component CrAlN [22]and TiAlN [13,23-24]coatings, with better corrosion resistance when compared with CrN or TiN coatings. The improved corrosion resistance of these coatings is related to the refinement of grain sizes caused by Al addition [16,24]. In addition, the number of pores and pinholes could be restricted

because of the formation of nanocrystalline phases, which further enhanced the corrosion resistance of SS. PVD coatings deposited on the surface of SS have been extensively investigated, however, little attention has been paid to the effect of tempered microstructure of such PVD coatings on the corrosion resistance. In the present work, AlCrN coatings were first deposited on the surface of 316L SS by arc ion plating, and were then vacuum annealed at 700°C, 800°C, and 900°C. The effect of phase evolution of AlCrN coatings on corrosion resistance was investigated.

2 Experimental details

2.1 Materials and PVD processes

The substrate material used in this study was a 316L stainless steel (the chemical composition is given in Table 1), which was cut into samples measuring 15 mm diameter $\times$ 3 mm thickness. Each sample was ground and polished to obtain a mirror-like surface, and then cleaned in acetone and ethanol using an ultrasonic cleaner for 15 min, respectively. The coatings were deposited in a M-AIP system by using cathode Cr targets (99.9% purity) and AlCr targets (70 at.% Al, 30 at.% Cr, 99.9% purity), and were then symmetrically installed on opposite sides of a barrel-shaped vacuum chamber wall. The chamber measured 700 mm diameter $\times$ 900 mm height. The distance between samples and targets was 200-250 mm. At the beginning of deposition, the chamber base pressure was decreased to 4×10^{-3} Pa and the chamber and substrates were rapidly heated and kept

at a temperature of 350 °C, simultaneously. Argon was then pumped into the chamber until a pressure of 0.2 Pa was reached (a steady flow-rate of 100 sccm was used). All substrates were cleaned in argon plasma for approximately 30 min using a bias voltage of –1000 V. After that, the Cr targets were worked for 20 min to obtain a Cr layer to enhance adhesion strength, the thickness of Cr layer was about 0.26 µm. During this period, the sample rotation speed was 2 rpm and the vacuum was held at 3×10^{-1} Pa, while the negative bias was changed to –900 V, the temperature was held at 450 °C. For the AlCrN coatings, closed Cr targets and open AlCr alloy targets were used, the arc current of the AlCr targets was 80 A at a voltage of 30 V: a negative bias of –200 V was used at a duty ratio of 80%. Argon was replaced by nitrogen at a flow rate of 80 sccm. Besides, the deposition was performed at 450 °C, at a nitrogen partial pressure of 1.2 to 1.5 Pa. The deposition times of the AlCrN coatings were fixed at 270 min: the overall thickness of the coating was about 3.4 µm. After deposition, the coated samples were annealed at 700°C, 800°C, and 900°C. The pressure in the annealing furnace was 7.5×10^{-2} Pa. The heating rates were 10 °C/min and 5 °C/min before, and after, reaching 650 °C, respectively. After annealing, the samples were cooled to room temperature in vacuum before being removed from the furnace to prevent oxidation.

2.2 Electrochemical measurements

The corrosion behaviour of the samples was investigated by conducting potentiodynamic polarisation measurements using a potentiostat Model CHI604D. A

conventional three-electrode cell with a counter electrode of platinum and a saturated calomel electrode (SCE) as a reference were used. All electrochemical tests were performed with a circular exposure surface (1.0 cm^2 in area) in 3.5-wt.% NaCl and 10-wt.% H_2SO_4 aqueous solution at room temperature. Potentiodynamic polarisation curves were measured at a scanning rate of 1 mV s^{-1} . The specimens were stabilised for 1 hour, in the solution, at open circuit voltage.

2.3 Characterisation methods

The adhesion strength of the coatings was confirmed by using a scratch test (HT-3001 scratch tester equipped with an acoustic emission detector) [25]. Surface morphologies were examined by scanning electron microscope (SEM, JSM-6490LV, 15.0 kV) with energy dispersive spectrometer (EDS). The crystalline structure of the coatings was analysed by X-ray diffraction (XRD, Bruker D8 advance X-ray diffractometer in a 2θ scan mode using $\text{CuK}\alpha$ radiation: 40 kV, 40 mA). The samples were scanned from 30° to 80° in 2θ mode at a scan rate of $2^\circ/\text{min}$. Thermo ESCALAB 250 X-ray photoelectron spectroscopy (XPS) was adopted to assess the chemical composition of the coatings. The atomic percents variation data of coatings with different etch times were used. The X-ray source adopted monochromatic Al K α ($h = 1486.6 \text{ eV}$) with 150 W, which was calibrated by carbon peak C 1s at 284.5 eV. Multi-reflection grazing incidence geometry (MGIXD, incidence angles α were 3°) was applied to measure near surface stress in AlCrN coatings. To ensure the collimated beam, the Rigaku SmartLab X-ray diffractometer (Cu K α

radiation) equipped with a Gobel mirror were adopted. The diffraction peaks of (Al,Cr)N phases ((111), (200), (220)) were used to calculate the residual stress data of the samples according to A. Baczmanski's method [26].

3 Results and discussion

3.1 Phase structures

XRD was performed to identify the phase structure of the deposited AlCrN coating and its phase evolution during the subsequent annealing processes (see Fig. 1). The as-deposited AlCrN coating was mainly composed of (Cr,Al)N solid solution phases with a face-centred cubic structure (fcc), without any compounds containing Al [27], and an austenitic (substrate phase) was also detected. In addition to this (Cr,Al)N phase, some AlN phases with a hexagonal close packed structure (hcp) were observed in the AlCrN coating annealed at 700 °C. It has been reported that the fcc-(Cr,Al)N decomposes to rich-Cr and rich-Al domains by a spinodal mechanism, and subsequently the latter transforms to an hcp-AlN phase due to its higher thermal stability during annealing [28]. Careful observation shows that the diffraction peaks of fcc-(Cr,Al)N phase shift towards a larger angle, which is related to relaxation of residual stress caused by the annealing treatment, as well as the formation of the hcp-AlN phase [29]. When the annealing temperature reached 800 °C, the peak intensity of the fcc-(Cr,Al)N phase decreased, and the peak intensity of the hcp-AlN phase increased; meanwhile, Fe-Cr intermetallic compounds (σ -FeCr phases) were observed. A similar phenomenon was also found in the

AlCrN coating annealed at 900 °C. It has been reported that, during higher temperature annealing, some Fe-Cr intermetallic compounds precipitate in 316L SS [30]. XRD was used to identify the formation of a σ -FeCr phases in the coating, or 316L SS substrate (Fig. 1b). The XRD patterns of uncoated 316L SS annealed at 800 °C showed no evidence of the formation of σ -FeCr phases. It could be concluded that the σ -FeCr phases were formed from coatings rather than from the substrates during vacuum annealing, as the Cr atoms from the coatings reacted with the Fe atoms from the 316L SS. Fig. 2 shows the atomic percents of the coatings before and after annealing with different etch times. With increasing the annealing temperature, the atomic percent of N element gradually decreased and the atomic percent of O element increased. The atomic percent of Al element was always higher than that of Cr element during the annealing process. It could be concluded that the nitrides on the coating surface decomposed and the Al_2O_3 formed in this period. The formation of an Al_2O_3 phase was beneficial to the corrosion resistance of AlCrN coatings [23,31].

3.2 Surface morphology

Fig. 3 shows the SEM surface morphologies of the AlCrN coatings after various treatment processes. As shown in Fig. 3a, it can be seen that many droplets and particles were present on the surfaces of as-deposited AlCrN coatings. These particles came from the droplets emitted by arc spots in the cathode targets [28,32-33]. EDS analysis showed that these particles were rich in Cr and Al, indicating that these particles were mainly

composed of Cr and Al pure metal, or Cr–Al alloy. As shown in Figs. 3b to d, the number, and grain sizes, of surface particles and droplets gradually decreased with increasing annealing temperature. This indicated that the solid metal droplets melted then blended into the coatings causing many holes to be filled. However, floccules appeared on the surface of those coatings annealed at 900 °C. EDS analysis showed, that the floccules were mainly rich in Cr, Al, which indicated that these floccules were mainly Al, Cr pure metal, or Cr–Al alloy. With increasing annealing temperature, Al pure metal and part of Cr–Al alloy were melted on the surface of coating, thus the floccules formed.

3.3 Adhesion strength

Generally, adhesion strength is an important when ensuring the practical utilisation of coatings. In this study, scratch tests were performed to evaluate the adhesion strength between the coatings and substrates. Each sample in the study was tested three times. Generally, the scratch test includes three stages: Lc1, Lc2, and Lc3 [25,34]. Lc1 was denoted as a critical load at which the first micro-cracking was observed (cycling of the friction); Lc2 was denoted as a crack propagation stage with some peeling of the coatings (rapid increase of the friction); and Lc3 was denoted as a critical load at which coatings peeled completely from their substrates. Generally, Lc2 was regarded as a sign of coating adhesion failure, and combining with acoustic signals, the adhesion strength could then be determined [35]. Fig. 4 shows typical friction-acoustic-load curves of AlCrN coatings after different treatment processes. Fig. 5 presents the adhesion strength error values of

coatings (the x-axis 450 °C denoted as as-deposited sample). For the as-deposited AlCrN coatings as shown in Fig. 4a, the Lc2 value was about 27.1 N. For the AlCrN coatings annealed at 700 °C, the Lc2 values reached 31.1 N, which indicated that annealing can considerably improve the adhesion strength of the AlCrN coatings onto their substrates. The improved adhesion strength is related to the reduction of residual stress caused by annealing [34]. The MGIXD patterns for residual stress measurement and the fitted data were shown in Fig. 6. (the x-axis 450 °C denoted as the as-deposited sample). The residual stress of the as-deposited coating was about -1170 MPa, but for samples annealed at 700 °C and 800 °C, the measured values were -960 MPa and -672MPa, respectively. The residual stress of sample annealed at 900°C was hard to obtain a exactly value due to its weak diffraction peaks, indicating the residual stress value further decreased. However, the Lc2 values of samples annealed at 800 and 900 °C decreased to 24.2N and 18.3N, respectively. This could be explained by the formation of negative σ -FeCr phases during annealing (and especially at 900 °C). In addition, new phases, such as the Cr₂N phase, were detrimental to adhesion due to their brittleness: this is why the adhesion strength decreased after annealing at 800 °C [34].

3.4 Corrosion behaviour

Fig. 7 shows the potentiodynamic polarisation curves of the AlCrN coatings and 316L SS annealed at 700 °C, 800 °C, and 900 °C in 3.5-wt.% NaCl solution. The electrochemical parameters measured from these curves are shown in Table 1. The corrosion potential (E_{corr}) of the 316L SS substrate was about -0.185 V. The as-deposited

AlCrN coatings revealed positive corrosion potential when compared with the 316L SS substrate, and the corresponding corrosion potential was about -0.148 V. This indicated that the as-deposited AlCrN coatings had better corrosion resistance than the 316L SS substrate. For the AlCrN coatings annealed at 700 °C, 800 °C, and 900 °C, the corrosion potentials corresponded to 0.158 V, 0.177 V, and -0.087 V, respectively, suggesting that subsequent annealing considerably improved their corrosion resistance when compared with the as-deposited AlCrN coatings: the AlCrN coatings annealed at 800 °C had the highest corrosion resistance of all of the coated samples. The polarisation curves of 316L SS after annealing at a range of temperatures are shown in Fig. 7. The corrosion potentials of annealed SS had not significantly improved compared with the unannealed substrate. This situation led to the conclusion that the annealing of SS had little effect on the corrosion resistance of coatings and the enhancement of the corrosion behaviour reflected the properties of the coatings themselves. Generally, the corrosion rate was inversely proportional to the corrosion current density (i_{corr}). For the 316L SS substrate, the corrosion current density was about $5.43 \times 10^{-7} \text{ A}\cdot\text{cm}^{-2}$, which fell to $2.37 \times 10^{-8} \text{ A}\cdot\text{cm}^{-2}$ for the as-deposited AlCrN coatings, indicating that the latter showed a lower corrosion rate in comparison with the SS substrate. It has been reported that the transition metal nitride coatings are electrochemically inert [20,21], and thus as-deposited AlCrN coatings revealed a higher polarisation resistance when compared with 316L SS. Furthermore, the as-deposited AlCrN coatings showed a nano-multilayer structure which gave rise to significant inhibition of pitting propagation [22,23]. For the samples annealed

at 700 °C, 800 °C, and 900 °C, the corrosion current densities were $1.22 \times 10^{-8} \text{ A}\cdot\text{cm}^{-2}$, $4.23 \times 10^{-9} \text{ A}\cdot\text{cm}^{-2}$, and $1.45 \times 10^{-8} \text{ A}\cdot\text{cm}^{-2}$ respectively. The reduction of corrosion current densities for the annealed samples was mainly associated with the formation of hcp-AlN phases as an insulator. So the samples annealed at 700 °C and 800 °C showed higher polarisation resistance and lower corrosion rates in comparison with the as-deposited sample. The sample annealed at 800 °C had a lower corrosion rate when compared to the sample annealed at 700 °C, which was owing to its higher hcp-AlN content. However, the sample annealed at 900 °C exhibited a higher corrosion rate in comparison to the sample annealed at 800 °C. The reduction of corrosion resistance was related to the precipitation of the σ -FeCr phase. Therefore, it can be concluded that the samples annealed at 700 °C and 800 °C were more suitable for industrial application.

As shown in Table 2, the E_{corr} and i_{corr} values of 316L SS were -0.185 V and $5.43 \times 10^{-7} \text{ A}\cdot\text{cm}^{-2}$, respectively. While the E_{corr} and i_{corr} values of as-deposited AlCrN coatings were -0.148 V and $2.37 \times 10^{-8} \text{ A}\cdot\text{cm}^{-2}$, respectively. The protection efficiency, P (%) was calculated as follows [13]:

$$P = 100 \times (1 - i_{\text{corr}}/i_{\text{corr}}^0) \quad (1)$$

where i_{corr} and i_{corr}^0 are the corrosion current densities in the presence, and absence, of a coating, respectively. The protection efficiency of the as-deposited coatings on the substrate reached 95.6%, and the relative corrosion rate ($i_{\text{R-C}}$) decreased more than 20-fold. The protection efficiency of coatings has been improved after vacuum annealing. However, the corrosion resistance increased at first and later decreased with increasing

temperature. Minimum i_{corr} and maximum R_p (polarisation resistance) values, achieved at 800 °C, were $4.23 \times 10^{-9} \text{ A}\cdot\text{cm}^{-2}$ and $9.18 \times 10^6 \text{ }\Omega\cdot\text{cm}^2$ respectively. The protection efficiency increased to 99.2% and $i_{\text{R-C}}$ decreased more than 120-fold at the same time. These results revealed that AlCrN coatings annealed at 800 °C had the optimum corrosion resistance against Cl^- ions, which was in accordance with the Tafel curves shown in Fig. 7.

The Tafel curves of the AlCrN coatings and 316L SS before, and after, annealing at various temperatures in 10-wt.% H_2SO_4 solutions are shown in Fig. 8. The sample annealed at 800 °C had the highest corrosion potential and lowest passive current density: this implied that the best corrosion resistance performance was found in 10-wt.% H_2SO_4 solution. Meanwhile, the samples annealed at 900 °C had the worst corrosion resistance due to their highest corrosion current density and lowest corrosion potentials, according to the polarisation curves. Therefore, based on the polarisation curves shown in Fig. 8, it was found that the corrosion resistance of AlCrN coatings in 10-wt.% H_2SO_4 solution initially increased, then decreased, with increasing temperature. The coating sample annealed at 800 °C had the best corrosion behaviour: coatings, rather than annealed SS, based on the same theory had the best corrosion resistance in NaCl solution.

Table 3 lists the fitted results based on the Tafel curves for AlCrN coatings before, and after, annealing, and uncoated 316L SS in 10-wt.% H_2SO_4 solutions. The i_{corr} and R_p values of 316L SS substrate in H_2SO_4 solution were $4.24 \times 10^{-7} \text{ A}\cdot\text{cm}^{-2}$ and $4.40 \times 10^4 \text{ }\Omega\cdot\text{cm}^2$, respectively. While i_{corr} decreased to $2.78 \times 10^{-7} \text{ A}\cdot\text{cm}^{-2}$ and R_p

increased to $1.27 \times 10^5 \Omega \cdot \text{cm}^2$ after being AlCrN-coated, its protection efficiency reached 33.3%, which revealed that as-deposited AlCrN coatings significantly enhanced the corrosion resistance of 316L SS. By contrasting the fitted data from the Tafel curves of AlCrN coatings annealed at different temperatures, it was found that samples annealed at 800 °C had the lowest i_{corr} of $6.58 \times 10^{-9} \text{ A} \cdot \text{cm}^{-2}$, and their R_p value had increased to $6.62 \times 10^6 \Omega \cdot \text{cm}^2$ at the same time. The protection efficiency was 98.4% and the relative corrosion rate decreased by about 65 times compared to the substrate. However, it was worth mentioning that the samples annealed at 900 °C performed poorly relative to the corrosion rates of other samples, and was even lower than that of uncoated 316L SS.

In conclusion, the as-deposited and annealed coatings both presented good corrosion resistance in 3.5-wt.%NaCl and 10-wt.% H_2SO_4 solutions compared with bare 316L SS substrates: coating corrosion resistance increased and then decreased with increasing annealing temperature. The coatings annealed at 800 °C had the best corrosion performance among the three series of samples.

From the previous analysis, the major ingredient of as-deposited AlCrN coatings was found to be an fcc-(Cr,Al)N phase: many droplets and particles were presented on the surface of the coatings. The (Cr,Al)N phase decomposed into hcp-AlN and CrN phases, the number of particles and droplets on the surface had decreased significantly after annealing at 700 °C. These droplets and particles on coatings annealed at 800 °C further diminished in number; this made it harder for corrosive media to pass through the coatings to make contact with the substrate. At this point, hcp-AlN, and σ -FeCr phases,

and small amounts of CrN, Cr₂N, and Al₂O₃ phases were the main components of these coatings. It is generally known that hcp-AlN, Al₂O₃, CrN, and Cr₂N phases have good corrosion resistance [36]; this is why samples annealed at 800 °C had the best corrosion resistance. The corrosion protection property become poorer after annealing at 900 °C, because CrN and Cr₂N phases were further decomposed to elemental Cr, which constantly formed σ -FeCr phase compounds with Fe atoms from the substrate diffused into the coatings. This σ -FeCr phase can accelerate corrosion of the coatings [30]. Particularly, elemental Cr, with Fe atoms, can easily form a galvanic cell system in an acid solution, which can further accelerate the corrosion of the coatings and then damage the substrate. Therefore, the coating annealed at 900 °C had a poor corrosion resistance, and indeed performed worse than the 316L SS substrate.

4 Conclusions

In this work, the chemical compositions, surface morphologies, adhesion strength, and corrosion resistance properties of AlCrN coatings before, and after, vacuum annealing were investigated. After vacuum annealing, a solid solution hcp-(Cr,Al)N phase of the AlCrN coating decomposed into hcp-AlN and CrN phases. With the increase of annealing temperature, the CrN phase further decomposed into N and Cr: the Cr and Fe atoms, which spread into the substrates, formed Fe-Cr phase (σ -FeCr phase) inter-metallic compounds. Many typical metal droplets and particles were found on the

surface of the as-deposited coatings: with the increased annealing temperature, the number of metal particles and droplets gradually diminished due to these solid metal droplets melting. According to scratch test results, AlCrN coatings had the highest binding strength of 31.1 N after 700 °C annealing and it decreased with 800 °C (from 31.1 N to 18.3 N at 900 °C). This could be explained by considering the σ -FeCr and Cr₂N phases generated, and the residual stress decreased during annealing. The potentiodynamic polarisation curves showed that the corrosion resistance of AlCrN coatings annealed at different temperatures was improved compared with 316L SS substrates. The coatings, after annealing at 800 °C, showed the best protective efficiency of 99.2% in 3.5-wt.% NaCl solution and 98.4% in 10-wt.% H₂SO₄ solution, respectively. This was caused by the hcp-AlN, Al₂O₃, CrN, and Cr₂N phases with good corrosion resistance generated after annealing at 800 °C.

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Figure captions

Figure 1 Typical XRD patterns of as-deposited AlCrN coatings and vacuum annealed coatings at temperatures of 700 °C, 800 °C, and 900 °C (a) and annealed 316L SS at 800 °C (b).

Figure 2 Atomic percents of the coatings before and after annealing with different etch times: as-deposited (a), 700 °C (b), 800 °C (c), 900 °C (d). Note that the data was obtained from XPS measurement.

Figure 3 Surface SEM micrographs of as-deposited AlCrN coatings (a) and coatings after vacuum annealing at temperatures of 700 °C (b), 800 °C (c), 900 °C (d).

Figure 4 Friction-acoustic-load curves of as-deposited AlCrN coatings (a) and coatings after vacuum annealing at temperatures of 700 °C (b), 800 °C (c), 900 °C (d).

Figure 5 The adhesion strength error values of as-deposited AlCrN coatings and annealed coatings.

Figure 6 The MGIXD patterns of AlCrN coatings before and after vacuum annealing (a) and the residual stress values of AlCrN coatings at various temperature (b).

Figure 7 Potentiodynamic polarisation curves of the AlCrN coatings and 316L SS before, and after, vacuum annealing in 3.5% NaCl solution.

Figure 8 Potentiodynamic polarisation curves of the AlCrN coatings and 316L SS before, and after, vacuum annealing in 10% H₂SO₄ solution.

Table 1

The chemical composition of 316L SS.

Cr	Ni	Mo	Mn	C	Si	P	S
19	13	2	1.5	0.02	1.0	0.03	0.02

Table 2

Potentiodynamic polarization data of the 316L SS and AlCrN coatings before and after vacuum annealing in 3.5% NaCl solution.

Specimen	E_{corr} (V)	i_{corr} (A·cm⁻²)	R_p (Ω·cm²)	i_{R-C}	$P(\%)$
316L	-0.185	5.43×10 ⁻⁷	7.28×10 ⁴	—	—
As-deposited	-0.148	2.37×10 ⁻⁸	1.26×10 ⁶	1/22.9	95.6
700°C	0.158	1.22×10 ⁻⁸	2.93×10 ⁶	1/44.5	97.8
800°C	0.177	4.23×10 ⁻⁹	9.18×10 ⁶	1/128.4	99.2
900°C	-0.087	1.45×10 ⁻⁸	2.67×10 ⁶	1/37.4	97.3

Table 3

Potentiodynamic polarization data of the 316L SS and AlCrN coatings before and after vacuum annealing in 10% H₂SO₄ solution.

Specimen	E_{corr} (V)	i_{corr} (A·cm⁻²)	R_p (Ω·cm²)	i_{R-C}	$P(\%)$
316L	-0.157	4.24×10 ⁻⁷	4.40×10 ⁴	—	—
<u>As-deposited</u>	0.099	2.78×10 ⁻⁷	1.27×10 ⁵	1/1.5	33.3
700°C	0.279	1.70×10 ⁻⁸	2.47×10 ⁶	1/24.9	96.0
800°C	0.375	6.58×10 ⁻⁹	6.62×10 ⁶	1/64.4	98.4
900°C	-0.346	2.10×10 ⁻⁵	1.68×10 ³	—	—