Aluminum and its alloys are protected from corrosion by an air-formed oxide film of several nanometers thickness. However, the protective ability of the air-formed oxide film is limited due to its small thickness. In order to obtain more reliable and durable protection for aluminum and its alloys, a relatively thick oxide film has been pursued. As a case in point, aerospace aluminum alloys are anodized in acidic electrolyte to produce a relatively thick anodic oxide film of a few micrometers, providing the alloys with reasonable corrosion resistance and/or suitable surface for painting and adhesive bonding. Chromic acid anodizing (CAA) used to be the most widely employed anodizing process in aerospace industry. However, the high toxicity associated with Cr (VI) has restricted the application of CAA. Since 1990s, there have been many efforts to find alternative anodizing process to replace CAA in aerospace industry. Sulfuric acid anodizing (SAA) is a commonly used, environmentally friendly anodizing process. However, a relatively thicker anodic film is needed for SAA than for CAA if the same corrosion resistance is required. On the other hand, increased film thickness will sacrifice fatigue resistance of the anodized components, not mentioning cost increase.

In 1990, Wong et al. invented a boric-sulfuric acid anodizing (BSA) process, which modifies the traditional SAA process by reducing the concentration of sulfuric acid and adding boric acid. It is now recognized that the performance of the anodic film produced by BSA is similar to that of the anodic film produced by CAA. At the begin of the twenty first century, a new anodizing process, called tartaric-acid anodizing (TSA), was patented by Alenia Aeronautica of the United Kingdom. The presence of tartaric acid did not change the film morphology, but increased the film uniformity. It was reported that the dissolution of the anodic film during anodizing led to increased pore size, rod-shaped cavities and grain boundary grooves in the anodic films. The rod-shaped cavities and grain boundary grooves are associated with selective dissolution of the anodic film formed from fine T1 (Al2CuLi) phase precipitates due to the difference in the reactivity of the films formed from different phases. The increased porosity due to dissolution degraded the corrosion resistance of the anodic film. In the temperature range of 22–47 °C, with 0.53 M tartaric acid addition, anodizing at 42 °C provided the best corrosion performance and a relatively high anodizing efficiency; in the tartaric acid concentration range of 0–0.9 M, at 37 °C, anodizing in electrolytes containing 0.7 and 0.9 M tartaric acid provided good corrosion resistance with little decrease of anodizing efficiency. The corrosive medium did not penetrate the anodic film uniformly but preferentially at local sites, resulting in localized corrosion of the anodized alloy.

The effect of anodization temperature and tartaric acid concentration on the morphology and corrosion resistance of the anodic film formed on AA2099-T8 alloy in tartaric-sulfuric acid was investigated. It was found that the dissolution of the anodic film during anodizing led to increased pore size, rod-shaped cavities and grain boundary grooves in the anodic films. The rod-shaped cavities and grain boundary grooves are associated with selective dissolution of the anodic film formed from fine T1 (Al2CuLi) phase precipitates due to the difference in the reactivity of the films formed from different phases. The increased porosity due to dissolution degraded the corrosion resistance of the anodic film. In the temperature range of 22–47 °C, with 0.53 M tartaric acid addition, anodizing at 42 °C provided the best corrosion performance and a relatively high anodizing efficiency; in the tartaric acid concentration range of 0–0.9 M, at 37 °C, anodizing in electrolytes containing 0.7 and 0.9 M tartaric acid provided good corrosion resistance with little decrease of anodizing efficiency. The corrosive medium did not penetrate the anodic film uniformly but preferentially at local sites, resulting in localized corrosion of the anodized alloy.

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The effect of TSA parameters on the morphology of the anodic films and the corrosion resistance of the anodized AA2099-T8 alloy are discussed in this communication. Specifically, anodization temperature and tartaric acid concentration, which require careful control during mass production, are the focus of this work. It was found that the morphology and corrosion resistance of the anodic film were sensitive to anodization temperature and tartaric acid concentration. Preferential dissolution of the anodic film formed from T₁ (Al₂CuLi) phase precipitates became prominent at higher temperature or with lower tartaric acid addition, resulting in rod-shaped cavities and grain boundary grooves in the anodic films. This work advances mechanistic understanding of the improved corrosion resistance of the TSA film, serving as a foundation for application of TSA to the new generation aluminum-lithium alloys.

Experimental

The AA2099-T8 alloy, containing (wt%) 1.69 Li, 2.7 Cu, 0.65 Zn, 0.265 Mg, 0.315 Mn, 0.065 Fe, 0.025 Ti, 0.08 Zr, 0.035 Si and remainder Al, was provided by CHINALCO. Specimens, of 50 × 25 × 2 mm dimensions, were mechanically ground with 400, 600, 800, 1200 and 2500 grit silicon carbide papers. Following mechanical grinding, the specimens were etched in a 10 wt% NaOH solution at 60°C for 300 s, and then desmutted in a 30 vol.% HNO₃ solution for 30 s, rinsed in deionized water and dried in a cold air stream.

TSA is typically carried out in 0.46 M sulfuric acid with addition of 0.53 M tartaric acid at 37°C, with the anodizing voltage being ramped up from 0 to 14 V in 5 min and then kept constant at 14 V for 20 min. Voltage ramping up will result in reduced pore size in the near-surface region of the anodic film, which may compromise the influence of the factors studied. Therefore, the voltage ramping up in the first 5 min was replaced with constant voltage anodizing at 14 V for 5 min in the present work. Thus, one group of the etched specimens was anodized at a constant voltage of 14 V for 25 min in the standard solution of 0.46 M sulfuric acid with addition of 0.53 M tartaric acid, at temperatures of 22, 27, 32, 37, 42 and 47°C, respectively; the other group of the etched specimens was anodized at a constant voltage of 14 V for 25 min, at 37°C, in 0.46 M sulfuric acid with addition of 0.01, 0.3, 0.53, 0.7 and 0.9 M tartaric acid, respectively. In order to control the solution temperature, the anodizing cell was put in a digital, electric heating water bath; at the same time the solution in the anodizing cell was magnetically stirred. The fluctuation of the solution temperature relative to the setting value was controlled to be ±1°C during each anodizing process.

Surface morphology of the specimens after different treatments was characterized using a field emission gun scanning electron microscope (FEG-SEM), fitted with energy dispersive X-ray (EDX) facilities, and operated at an accelerating voltage of 2 kV. The corrosion resistance of the anodized alloy was assessed using neutral salt spray test (NSST). The NSST was carried out by referring to ASTM B117-91, with continuous spraying of 5 wt% NaCl solution at pH of 6.5 and temperature of 35 ± 1°C. The NSST was stopped for about 10 min every 12 h to visually examine the specimen, and was completely terminated after 48 h of exposure when evident localized corrosion was visually detected on all tested specimens. The NSST was repeated for one cycle to assure reproducibility. Cross sections of selected specimens before and after NSST were prepared by immersing the specimens in liquid nitrogen and then bending from a pre-made notch on the opposite side to the anodic film.

Results

Alkaline etched surface.—Alkaline etching is widely employed as a surface pre-treatment for anodizing aluminum and its alloys, providing treated products with clean surface with matte appearance. As a result of alkaline etching, a nanotexture develops on the surface of the treated alloy (Figure 1). Previous work indicates that the nanotexture is associated with copper-rich nanoparticles in the copper-enriched layer beneath the residual oxide film formed during the etching.

discussed later, the nanotexture can be used as an indicator for assessing the extent of dissolution of the anodic film during anodizing.

Effect of anodization temperature.—Figure 2 shows current density-time responses of the first 300 s during anodizing of the alloy in standard TSA solution at 14 V, at various temperatures. Parameters associated with the anodizing under the selected conditions are compared in Table 1. The film thickness was directly measured from the cross sections of the films in FEG-SEM, with the average of three measurements being listed. The film growth rate was calculated by dividing the measured film thickness by the anodization time (1500 s). The current density came to be steady after about 150 s for all conditions. For comparison, the current density after 300 s was chosen as the steady current density for all the conditions in this work. As shown in Table 1, with the increasing anodization temperature, film growth rate increased gradually from 1.3 nm/s at 22°C to 4.6~4.7 nm/s at 47°C; the steady current density also increased with the anodization temperature from 2.6 mA/cm² at 22°C to 12.0 mA/cm² at 47°C.

Surface morphology of the anodic films was examined in FEG-SEM, as shown in Figure 3. The nanotexture feature resembling that shown in Figure 1, in addition to porous morphology of the anodic film, is revealed on the surface of the anodic film formed at 22°C (Figure 3a). When the anodization temperature was increased to 27°C,
Table I. Parameters associated with anodizing AA2099-T8 alloy at 14 V and different temperatures for 25 min in the standard TSA electrolyte.

| Temperature (°C) | 22   | 27   | 32   | 37   | 42   | 47   |
|------------------|------|------|------|------|------|------|
| Film thickness (nm) | 1971 ± 6 | 2104 ± 59 | 3151 ± 6 | 4661 ± 28 | 5835 ± 191 | 6983 ± 41 |
| Growth rate (nm/s) | ~1.3 | ~1.4 | ~2.1 | ~3.1 | 3.8~4.0 | 4.6~4.7 |
| Steady current density (mA/cm²)* | 2.6 | 4.2 | 5.1 | 7.0 | 9.8 | 12.0 |

*The current density after anodizing for 300 s was chosen as the steady current density.

the nanotexture feature was still recognizable (Figure 3b), though not as clear as that at 22°C. At higher anodization temperatures, i.e. 32, 37, 42 and 47°C, the nanotexture feature completely disappeared while grain boundary grooves appeared (as indicated by the arrows in Figures 3c–3f). In addition, the pore diameter of the anodic film slightly increased with increasing anodization temperature. According to the classical film growth mechanism,28 the outmost surface of the anodic film corresponds to the original surface before anodizing, if dissolution of the anodic film in the anodizing bath is negligible. Therefore, the presence of the nanotexture feature on the surfaces of the alloy anodized at 22 and 27°C indicated that dissolution of the anodic film was negligible under the selected conditions; while the absence of the nanotexture feature under higher temperature conditions suggested that dissolution of the anodic film became pronounced with increasing temperature. The pore diameter which is proportional to the applied voltage (14 V for all conditions) should be the same for all the conditions. Therefore, the increasing pore diameter with increasing anodization temperature just confirms that dissolution rate of
the anodic films increased with increasing temperature. Rod-shaped cavities appeared on the surface of the anodic film formed at 37°C (indicated by the circles in Figure 3d) and such cavities became distinct at 42°C (Figure 3e). Due to increased dissolution at 47°C, the rod-shaped cavities merged with pores in the bulk anodic film, resulting in irregularly-shaped cavities (Figure 3f). The distribution of the rod-shaped cavities in Figure 3e was identical to that of fine T1 phase precipitates in the alloy matrix (Figure 4), suggesting that the rod-shaped cavities resulted from selective dissolution of the anodic film formed from T1 phase. The revealing of the rod-shaped cavities in the anodic films formed at 37, 42 and 47°C suggested that such selective dissolution tended to occur at relatively high anodization temperatures. Since the main grain boundary precipitates in AA2099-T8 alloy are T1 phase, the anodic films formed from the grain boundary regions were also more susceptible to dissolution in the anodizing bath compared to the film formed from the grain matrix at relatively high temperatures, leading to the development of grain boundary grooves in the anodic film.

The corrosion resistance of the anodic films formed at 14 V, at different temperatures, in the standard electrolyte was assessed using NSST. In order to qualitatively compare the extent of corrosion attack in the anodized alloy, the severity of corrosion attack was arbitrarily defined as n (n = 0, 1, 2…8), with 0 indicating no visible corrosion attack while 8 indicating most severe corrosion attack. Note that n does not reflect the corrosion resistance of the anodic film material itself because the overall corrosion resistance of the anodized alloy is related to not only the structure but also the thickness of the anodic film. In order to determine the corrosion resistance of the anodic film, a parameter R which equals to the reciprocal of n divided by film thickness (in micrometer) was used. R was calculated when evident corrosion attack (n = 1) was visually detected on the specimen with the best corrosion performance. The extent of corrosion attack of the specimens after NSST for up to 48 h is shown in Table II. The specimen anodized at 42°C provided the best corrosion performance, followed by the specimen anodized at 37°C. The specimens anodized at 22, 27, 32 and 47°C had relatively poor corrosion resistance.

Table II indicates that R decreases with the increase of anodization temperature except for the specimen anodized at 42°C, which had the largest R. This is particular interesting because the film growth rate under the condition was also relatively large. In other words, other anodizing parameters constant, anodizing at 42°C can provide not only the best corrosion performance but also a high anodizing efficiency. In order to clarify this, the film morphology and corrosion resistance of the specimens anodized at 40 and 44°C was compared with that anodized at 42°C. The morphology of the anodic film formed at 40 and 44°C was similar to that formed at 37 and 47°C, with film thicknesses of 4952 ± 135 and 6844 ± 74 nm, respectively. The R (36 h) for 40 and 44°C was 0.05 and 0.07, respectively, confirming the outstanding performance of the specimen anodized at 42°C.

**Effect of tartaric acid concentration.**—Figure 5 shows current density-time responses of the first 300 s during anodizing AA2099-T8 alloy in 0.46 M sulfuric acid solution, at 14 V and 37°C, with addition of 0, 0.1, 0.3, 0.53, 0.7 and 0.9 M tartaric acid, with Table III showing the associated parameters. As shown in Table III, with the increasing tartaric acid concentration, film growth rate initially increased and then decreased, reaching the highest value of 3.3–3.4 nm/s with 0.1 or 0.3 M tartaric acid addition, and the lowest value of 2.6–2.7 nm/s with 0.9 M tartaric acid addition; the steady current density was at the highest value of 9.0 mA/cm² with 0.1 M and the lowest value of 7.0 mA/cm² with 0.53 M tartaric acid addition.

The surface morphology of the alloy anodized in different electrolytes was examined in FEG-SEM (Figure 6). No surface nanotexture was revealed on all the specimen surfaces, suggesting relatively strong dissolution of the anodic film during anodizing. Without addition of tartaric acid, just like the anodic film formed in the standard electrolyte at 47°C (Figure 3f), the rod-shaped cavities associated with selective dissolution of the anodic film formed from T1 phase merged with pores of the bulk anodic film, forming irregularly-shaped cavities (as indicated by the arrows in Figure 6a). Selective dissolution of the anodic film associated with T1 phase was slowed down with increasing tartaric acid concentration from 0.1 to 0.7 M, as suggested by gradually reduced size and/or population density of the rod-shaped cavities. No evident rod-shaped cavities or grain boundary grooves

![Figure 4. The high angle annular dark field image (Z-contrast) of AA2099-T8 alloy, showing distribution of T1 (Al₂CuLi) phase.](image-url)

![Figure 5. Current density-time responses of the first 300 s recorded during anodizing AA2099-T8 alloy at 14 V and 37°C in 0.46 M sulfuric acid solution containing tartaric acid of various concentrations.](image-url)
Table III. Parameters associated with anodizing of AA2099-T8 alloy at 14 V and 37°C for 25 min in 0.46 M sulfuric acid solution containing tartaric acid of various concentrations.

| Tartaric acid (M) | 0    | 0.1  | 0.3  | 0.53 | 0.7  | 0.9  |
|-------------------|------|------|------|------|------|------|
| Film thickness (nm) | 4743 ± 30 | 5020 ± 78 | 5037 ± 21 | 4661 ± 28 | 4447 ± 107 | 3992 ± 84 |
| Growth rate (nm/s) | 3.1~3.2 | 3.3~3.4 | 3.3~3.4 | ~3.1 | 2.9~3.0 | 2.6~2.7 |
| Steady current density (mA/cm²)* | 7.9 | 9.0 | 8.1 | 7.0 | 7.5 | 7.5 |

*The current density after anodizing for 300 s was chosen as the steady current density.

were detected on the alloy anodized in the electrolyte containing 0.9 M tartaric acid.

The degree of corrosion attack of the alloy anodized in electrolytes containing different concentrations of tartaric acid, at 14 V and 37°C, after NSST for up to 48 h, is shown in Table IV. The alloy anodized in the electrolytes containing 0.7 and 0.9 M tartaric acid, respectively, had the best corrosion resistance, followed by the alloy anodized in the electrolyte containing 0.53 M tartaric acid. The alloy anodized in other electrolytes had relatively poor corrosion resistance.

Figure 7 shows optical photographs of the alloy anodized at 14 V and various temperatures in standard TSA solution, after NSST for 48 h. The brown/gray patches are deposited corrosion product. Some of the severe localized corrosion sites were indicated by the arrows in Figure 7. Figure 8 shows secondary electron micrographs of the alloy anodized at 14 V and 47°C in standard TSA solution, after NSST for 48 h. Cracks (Figure 8a) and flake-like features (Figure 8b) were revealed in most regions of the anodic film, suggesting sealing of the anodic film by the sodium chloride solution. Localized corrosion in

Figure 6. Secondary electron micrographs of AA2099-T8 alloy anodized at 14 V and 37°C in 0.46 M sulfuric acid solution containing (a) 0, (b) 0.1, (c) 0.3, (d) 0.53, (e) 0.7, and (f) 0.9 M tartaric acid.
the anodized alloy was typified either by a corrosion product dome (Figure 8c) or a deep cavity (Figure 8d). EDX analysis of the corrosion product dome in Figure 8c yielded 39.8 wt% Al, 35.7 wt% O and 24.5 wt% Cl. Cross sectional view of the anodized alloy before and after NSST is shown in Figure 9. A uniform, porous anodic film was evident before NSST (Figure 9a). However, a modified outer layer of 1~2 μm thickness was formed after NSST for 48 h (Figure 9b), confirming sealing of the porous anodic film by the sodium chloride solution. Below the sealing layer, typical porous anodic film was revealed and no sign of corrosion attack was detected in the alloy matrix immediately beneath the anodic film (Figure 9c). In the region of localized corrosion, however, the alloy matrix was severely attacked. Figure 9 suggests that the corrosive medium penetrated the anodic film and reached the alloy matrix in local regions, leading to initiation and propagation of localized corrosion in the anodized alloy. The detailed mechanism for initiation and propagation of localized corrosion in the anodized alloy is beyond the scope of the present paper and will be reported elsewhere.

Discussion

Table I indicates that the film thickness or film growth rate increased with increasing temperature within the selected temperature range of 22~47 °C. Additionally, increased temperature also resulted in increased dissolution of the anodic film, therefore, increased pore size. Further, when the anodization temperature was at or above 37 °C, selective dissolution of the anodic film formed from T1 phase precipitates occurred in addition to general dissolution of the bulk anodic film. This, as a consequence, further increased the porosity of the resultant anodic film. Therefore, the corrosion resistance of the anodic film, R, should decrease with increasing anodization temperature. However, as shown in Table II, R (36 h) did not monotonously decrease with increasing anodization temperature. R decreased from 0.13 at 22 °C to 0.10 at 27 °C, 0.08 at 32 °C and 0.07 at 37 °C; it then increased to 0.17 at 42 °C before it dramatically dropped to 0.02 at 47 °C. This suggests that other factor(s) in addition to film porosity contributed to the corrosion resistance of the anodic film.

Since tartaric acid concentration is the same (0.53 M) for all temperatures, the influence of tartaric acid concentration in electrolytes can be excluded. It is known that acid anions can be incorporated into the anodic film during anodizing and many anodic film properties such as ionic and electronic conductivities are known to be modified or controlled by the nature of acid anion incorporated. The level of incorporated tartrate ions in the anodic film and the influence of temperature on the level of incorporation are not available yet. It is reported that the level of incorporated sulfate ranges from 5% to 15% in films produced in sulfuric acid and may increase with lower anodization temperature. Therefore, whether the incorporated anions in the anodic film contributed to the corrosion resistance of the anodic film requires further investigation. Another possibility is that there might be a critical film thickness for the anodized alloy to possess reasonably good corrosion resistance. This is because there are micrometer scale defects in the bulk anodic film due to anodizing of intermetallic particles. The film thickness formed at 42 °C (5835 ± 191 nm) was close to or above the critical film thickness, leading to good corrosion resistance even when the porosity of the anodic film was relatively high. Although the anodic film formed at 47 °C was even thicker (6983 ± 41 nm), the highly increased dissolution of the anodic film at 47 °C degraded its corrosion resistance.

Table IV shows that the corrosion resistance of the anodic film, R, increased with the increasing tartaric acid concentration. The increasing tartaric acid concentration also resulted in reduced dissolution of the bulk film and the anodic film formed from T1 phase. The reason that tartaric acid suppressed the dissolution of the bulk anodic film and

| Tartaric acid (M) | 0   | 0.1 | 0.3 | 0.53 | 0.7  | 0.9  |
|------------------|-----|-----|-----|------|------|------|
| *n (12 h)        | 1   | 2   | 2   | 1    | 0    | 0    |
| n (24 h)         | 5   | 3   | 3   | 2    | 1    | 1    |
| n (36 h)         | 6   | 4   | 4   | 3    | 2    | 2    |
| n (48 h)         | 8   | 5   | 5   | 4    | 3    | 3    |
| *R (24 h)        | 0.04| 0.07| 0.07| 0.11 | 0.22 | 0.25 |

*n indicates the severity of corrosion attack (n = 0, 1, 2...8), with 0 indicating no visible corrosion attack while 8 indicating most severe corrosion attack; R equals to the reciprocal of n divided by film thickness in micrometer.

Figure 7. Optical photographs of AA2099-T8 alloy anodized at 14 V and various temperatures in standard TSA solution, after neutral salt spray test for 48 h. The arrows indicate some of the severe localized corrosion sites.
Figure 8. Secondary electron micrographs of AA2099-T8 alloy anodized at 14 V and 47°C in standard TSA solution, after neutral salt spray test for 48 h: (a) general film surface at low magnification; (b) the framed region in (a) at increased magnification; and (c, d) typical severe localized corrosion sites.

Figure 9. Secondary electron micrographs of the cross sections of AA2099-T8 alloy anodized at 14 V and 47°C in standard TSA solution: (a) bulk anodic film before NSST; (b) outer region of the anodic film after NSST for 48 h; (c) inner region of the anodic film after NSST for 48 h; and (d) the localized corrosion region.
the anodic film formed from T1 phase may be associated with the complexing action between anions from tartaric acid and cations from the alloy.16 The formed complex compound was absorbed on the porous film surface, leading to reduced dissolution rate of the anodic film. The reduced dissolution of the anodic film (therefore reduced porosity) was at least partially responsible for the improved corrosion resistance of the anodic films with increasing tartaric acid concentration. In addition, as suggested in Refs. 15 and 16, residual tartaric acid exists in the pores of the anodic film and the residual tartaric acid is beneficial for corrosion resistance of the anodic film. Therefore, increased tartaric acid concentration in the residual electrolyte in the pores of the anodic film further contributed to the improved corrosion resistance of the anodic film with increasing tartaric acid concentration.

As shown in Figures 3 and 6, rod-shaped cavities and grain boundary grooves were formed in the anodic film when anodizing in the standard electrolyte at or above 37°C, or anodizing at 37°C but with tartaric acid addition below 0.53 M. This was associated with selective dissolution of the anodic film formed from fine T1 phase precipitates compared to the difference in the reactivity of the films formed from the different phases. This indicates that the local film composition is determined by the composition of the fine precipitates that form the film, and the local film composition doesn’t change significantly during the course of anodizing. Previous work33–35 indicates that lithium and magnesium cations are highly soluble in acidic anodizing electrolytes, and magnesium cations were ascribed to reduced dissolution of the anodic film in the pores of the anodic film. Therefore, increased tartaric acid concentration in the residual electrolyte in the pores of the anodic film further contributed to the improved corrosion resistance of the anodic film with increasing tartaric acid concentration.

Conclusions

1) When anodizing AA 2099-T8 alloy in the standard TSA electrolyte at 14 V, the film growth rate increased gradually as anodization temperature increased from 3.3–3.4 nm/s with 0.1 or 0.3 M tartaric acid addition, and the lowest value of 2.6–2.7 nm/s with 0.9 M tartaric acid addition; the steady current density was at the highest value of 9.0 mA/cm² with 0.1 M and the lowest value of 7.0 mA/cm² with 0.53 M tartaric acid addition; the dissolution of the anodic film in the anodizing bath increased with the increasing anodization temperature. The specimen anodized at 42°C provided the best corrosion performance during neutral salt spray test.

2) When anodizing in 0.46 M sulfuric acid solution at 14 V and 37°C, the film growth rate initially increased and then decreased with increasing tartaric acid concentration, reaching the highest value of 3.3–3.4 nm/s with 0.1 or 0.3 M tartaric acid addition, and the lowest value of 2.6–2.7 nm/s with 0.9 M tartaric acid addition; the steady current density was at the highest value of 9.0 mA/cm² with 0.1 M and the lowest value of 7.0 mA/cm² with 0.53 M tartaric acid addition; the dissolution of the anodic film in the anodizing bath decreased with the increasing tartaric acid concentration. The specimen anodized in the electrolytes containing 0.7 and 0.9 M tartaric acid provided the best corrosion performance during neutral salt spray test.

3) When anodizing in the standard electrolyte at or above 37°C, or anodizing at 37°C but with tartaric acid addition below 0.53 M, rod-shaped cavities and grain boundary grooves were generated in the anodic films, which are associated with selective dissolution of the anodic film formed from fine T1 phase precipitates due to the difference in the reactivity of the films formed from the different phases.

4) Addition of tartaric acid to sulfuric acid improved the corrosion resistance of the anodic film. The beneficial effect of tartaric acid was ascribed to reduced dissolution of the anodic film in the anodizing bath, and was also related to the residual tartaric acid in the pores of the anodic film.

5) Sodium chloride solution had a sealing effect on the porous anodic film during neutral salt spray test, resulting in a modified surface layer of 1–2 μm thickness. The corrosive medium did not penetrate the anodic film uniformly but preferentially at local sites, resulting in localized corrosion of the anodized alloy.

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