Pitting Corrosion of Stainless Steel 430 in the Presence of Thin MgCl₂ Solution Films: Effects of Film Diameter and Thickness

Tran Van Nam¹,², Eiji Tada and Atsushi Nishikata

Department of Chemistry and Materials Science, Tokyo Institute of Technology, Tokyo 152-8552, Japan

The pitting corrosion of Type 430 stainless steel under thin MgCl₂ solution films was investigated under different relative humidities (RHs) to clarify the effect of film dimensions on this property. Thickness and diameter of the solution film were varied within 1–70 µm and 1–13 mm, respectively. No pitting corrosion was detected above 85% RH for all film dimensions. Below 75% RH, the probability of pitting corrosion occurrence decreased with decreasing diameter and thickness. No pit growth occurred when the diameter was approximately 1 mm.

Keywords: stainless steel, chloride, polarization, atmospheric corrosion, pitting corrosion

1. Introduction

In marine atmospheric environments, airborne salts are deposited on the stainless steel surface. At night, when the relative humidity (RH) increases and temperature decreases, the moisture in the air may condense and form chloride solution droplets and films on the surface. In contrast, during daytime, the chloride ion concentration increases with water evaporation. Highly concentrated chloride solution films enhance the pitting corrosion probability.¹⁻³ The chloride concentration in the solution film is determined from RH at equilibrium.⁴ Thus, the pitting corrosion of stainless steel proceeds below a critical relative humidity RHcr. Reported RHcr values equal ca. 65% and 75% for Types 304 (SS304) and 430 stainless steels (SS430), respectively.⁴⁻⁵ Equilibrium chloride concentrations in solution films amount to 6.2 and ca. 4.9 M for 65% and 75% RH, respectively. Recently, the pitting corrosion of stainless steel in atmospheric environments has attracted significant attention. Tsutsumi et al.⁵ and Hastuty et al.⁶ have studied the pitting mechanism of SS304 and SS430 under thin chloride solution films. The formed pits were shallow, indicating their preferential propagation in the horizontal direction. Ghabari et al.⁷⁻⁸ have monitored pit growth in stainless steel in situ under electrochemical control in chloride solutions. They found that corrosion pit propagation depended on steel microstructure and tended to follow the rolling direction probably in association with sulphide inclusions. Maier et al.⁹ have investigated the pitting behaviour of SS304 under droplets using a Kelvin probe. At low chloride concentration, the probability of pitting was higher under a large drop than under a small drop, suggesting that higher electrolyte coverage increases the higher probability of covering more susceptible defects. Burstein et al.⁹ measured pitting potential using different size of 316 stainless steel in HCl solution. They reported that pitting potential increases by decrease in the surface area of the specimen for the same reason.

Not only environmental factors but also material factors play important roles for the onset of pitting corrosion. Stainless steel surface inclusions, especially MnS, are known to act as initiation sites for pitting corrosion.⁴⁻¹⁰ Their anodic dissolution may produce a locally aggressive solution around the inclusion and lead to breakdown of the passive film. Chiba et al.¹⁷ have examined pit growth by microscopy during potentiodynamic anodic polarization in bulk chloride solution. The steel matrix side of MnS/matrix boundaries dissolved because of synergistic effects between elemental sulphur and chloride ions, resulting in trenches that expanded vertically.

Previous studies have indicated that pitting corrosion occurred at critical chloride concentrations of approximately 4.5 and 6 M for SS430 and SS304, respectively, under relatively thick solution films (> 5 µm) and in bulk solutions.¹¹⁻¹³ The pitting probability tended to decrease with decreasing solution film diameter and film thickness.¹³ This study focused on the effect of solution film dimensions on the pitting corrosion probability of SS430. The critical diameter and thickness of the solution film were determined for pitting corrosion occurrence, and the initiation and growth mechanisms of these pits were discussed.

2. Experimental

2.1 Pitting corrosion test under solution films

The pitting corrosion test under solution films has been described in detail.¹³ Specimens were prepared from commercial SS430 plates (100 mm × 100 mm × 4 mm). The chemical composition is shown in Table 1. The specimen surface was ground to a 300-grit surface using silicon carbide sandpaper. Five droplets of MgCl₂ solution with an initial volume V₀ ranging from 0.1 to 200 µL and initial chloride concentration

| Table 1 Chemical composition (mass%) of Type 430 stainless steel. |
|------------------|---|---|---|---|---|---|---|
| C    | Si  | P   | S   | Mn | Ni | Cr | Fe  |
| mass% |     |     |     |    |    |    |     |
| 0.081 | 0.52 | 0.033 | 0.006 | 0.31 | 0.12 | 16.2 | Bal. |
of 1 to 100 mM were randomly deposited on the specimen surface with micropipette. The specimen was kept at 95% RH and 298 K for 16 h in a humidity- and temperature-controlled chamber, enabling water evaporation from the droplet until the chloride concentration \([\text{Cl}^-]\) reached an equilibrium value of approximately 2 M.\(^4\) In Fig. 1, the relation between RH and \([\text{Cl}^-]\) at equilibrium is shown.\(^4\) It can be found that the equilibrium \([\text{Cl}^-]\) in the solution film at 95% RH is 2 M. Previous studies\(^1,4,5\) have shown that no pitting corrosion occurs at 95% RH. Next, RH was rapidly lowered to 85%, 75%, 65%, 55%, 45% and 35% and maintained at these individual levels for 6 h. This corrosion test was performed at 298 K.

The presence of pits was confirmed by the naked eye. Red rust spots indicated the formation of large pits. In the absence of red rust, the exposure time period was extended to 24 h, and the pits were examined by digital microscopy at ×3000 magnification. In this test, only pits exhibiting diameters larger than 10 µm were counted. Rapidly repassivated pits presenting diameters below several micrometres were not considered in this study because the size was similar to dimension of MnS inclusions on the employed SS430 surface. The diameter \((X_d)\) of the droplet placed on the SS surface was determined using the empirical equation:\(^5\)

\[
X_d = 2.3(V_0)^{0.28}
\]

(1)

When RH was reduced, the droplet thickness decreased but the diameter remained intact, producing a disk-shaped solution film. The final equilibrium thickness \(X_e\) was calculated by:

\[
X_e = (V_0[\text{Cl}^-]_0)/(\pi(X_d/2)^2[\text{Cl}^-]_\text{eq})
\]

(2)

where \([\text{Cl}^-]_0\) and \([\text{Cl}^-]_\text{eq}\) are the initial and equilibrium concentrations of chloride ions, respectively. \(V_0/\mu\text{L}\) is the initial volume \((V_0 = 0.1, 0.3, 0.5, 2.0, 20, 50, 100, 150, 200 \mu\text{L})\). Uniform solution films did not seem to be formed due to surface tension when the thickness was below ca. 1 µm, especially for larger diameters. The equilibrium chloride concentration ranged between 2 and 9.5 M (Fig. 1).

2.2 Electrochemical measurements

To explain the pitting corrosion behaviour under thin solution films, cathodic and anodic polarization curves were measured under MgCl\(_2\) solution films and in bulk MgCl\(_2\) solutions at 298 K. Cathodic polarization measurements were performed using a three-electrode cell arrangement under a thin electrolyte layer (Fig. 2). The working electrode was an SS430 plate \((1 \text{ mm} \times 10 \text{ mm})\), whereas platinum \((1 \text{ mm} \times 10 \text{ mm})\) and silver plates \((1 \text{ mm} \times 1 \text{ mm})\) acted as counter and reference electrodes, respectively. All electrodes were embedded parallelly each other with 0.5 mm apart in an epoxy resin. The end surface was ground to a 4000 grit surface and ultrasonically cleaned in distilled water. The cell was immersed in a 0.1 M HCl solution and then the Ag reference electrode was galvanostatically polarized at 4 A m\(^{-2}\) for 1800 s to deposit AgCl on the surface. After that, it was ultrasonically cleaned in distilled water. A small reference electrode was employed to minimize this effect because Ag could dissolve as the complex ion AgCl\(_2^-\) under highly concentrated chloride solution films. All reported potentials correspond to potentials vs. a saturated KCl Ag/AgCl reference electrode (SSE) in this study. The cathodic polarization curve on the SS430 electrode was measured for different thicknesses \((10–100 \mu\text{m})\) and chloride concentrations \((1–5 \text{ M})\). The cathodic polarization was achieved potentiodynamically from OCP to −1.2 V vs. SSE. In the polarization measurements under thin solution films, the solution chemistry will change.\(^20\) Thus the relatively high potential scan rate \((10 \text{ mV/s})\) was used to minimize the solution chemistry change in this study.

To determine the pitting potential \(E_{\text{pit}}\) and passive current density \(i_{\text{pass}}\) of SS430 in concentrated chloride solutions, the anodic polarization curves were measured in 2–5 M chloride bulks using a conventional three-electrode cell. The same potential scan rate \((10 \text{ mV/s})\) as the cathodic polarization under thin solution films was used to measure the \(i_{\text{pass}}\). The slower scan rate \((0.5 \text{ mV/s})\) was employed to determine the \(E_{\text{pit}}\). To prevent crevice corrosion, the SS430 working electrode was electropainted by an organic resin and cured at 443 K for at least \(1.2 \times 10^3\) s before being embedded in the epoxy resin.

![Fig. 1](image1.png)

**Fig. 1** Relative humidity (RH) at equilibrium for MgCl\(_2\) solutions of various chloride concentrations at 300 K.\(^4\)

![Fig. 2](image2.png)

**Fig. 2** Schematic of the three-electrode electrochemical cell. (1) Pt counter electrode, (2) SS430 working electrode, (3) Ag/AgCl reference electrode and (4) epoxy resin. (a) Top view and (b) transverse cross-sectional view.
the critical RH \( \text{crit} \) and \( [\text{Cl}^-] \) for the pitting corrosion of the employed SS430 was found to be between 1.5 and 1.9 mm. However, this critical value may also depend on thickness of the solution film.

To identify these thickness effects, pitting corrosion tests were conducted under solution films with different thicknesses but the same diameter \( (X_d = 1.6 \text{ mm}) \). Results are shown in Table 3. Above 55% RH, no pitting corrosion was observed for all thicknesses. At 35% and 45% RH, pitting corrosion did not occur under a 1.7-mm-thick film but was observed under ten (17 \( \mu \text{m} \)) and hundred (170 \( \mu \text{m} \)) times thicker films. Figure 3 shows a photograph of a pit formed on the SS430 surface under a 1.6-mm-diameter and 17-\( \mu \text{m} \)-thick film at 35% RH. This growth-type pitting displayed a diameter exceeding 90 \( \mu \text{m} \).

The critical diameter for pitting corrosion occurrence was expected to be much smaller than 1.6 mm for \( X_d \) values exceeding 10 \( \mu \text{m} \). Consequently, a pitting corrosion test was performed at a diameter of ca. 1 mm and showed no pitting corrosion regardless of thickness and RH (Table 3). This indicates that the critical diameter of chloride solution films for the pitting corrosion of the employed SS430 was approximately 1 mm. Mi et al.\(^{21}\) reported that pitting corrosion occurred on SS304 surface under 0.5 mm diameter MgCl\(_2\) solution film at 45 and 55% RH. In their experiment, MgCl\(_2\) crystals were deposited on the surface by an inkjet printing method, and then allowed to deliquesce at 90% RH before pitting corrosion tests. Accordingly, the salt deposits

### Table 2 Pitting probability under MgCl\(_2\) solution films for various diameter \((X_d)\) and thickness \((X_t)\) combinations at different relative humidities (chloride concentrations).

<table>
<thead>
<tr>
<th>( X_d ) (mm)</th>
<th>35%RH ([\text{Cl}^-]=9.5 \text{ M})</th>
<th>45%RH ([\text{Cl}^-]=8.5 \text{ M})</th>
<th>55%RH ([\text{Cl}^-]=7.4 \text{ M})</th>
<th>65%RH ([\text{Cl}^-]=6.2 \text{ M})</th>
<th>75%RH ([\text{Cl}^-]=4.9 \text{ M})</th>
<th>85%RH ([\text{Cl}^-]=3.0 \text{ M})</th>
</tr>
</thead>
<tbody>
<tr>
<td>( X_t ) (µm)</td>
<td>( N_{pit} / N_{total} )</td>
<td>( X_t ) (µm)</td>
<td>( N_{pit} / N_{total} )</td>
<td>( X_t ) (µm)</td>
<td>( N_{pit} / N_{total} )</td>
<td>( X_t ) (µm)</td>
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<td>13.7</td>
<td>14.2</td>
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<td>15.9</td>
<td>5/5</td>
<td>18.2</td>
<td>4/5</td>
</tr>
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<td>13.5</td>
<td>5/5</td>
<td>15.1</td>
<td>5/5</td>
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<td>5/5</td>
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<td>5.4</td>
<td>4/5</td>
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<tr>
<td>1.3</td>
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<td>0/5</td>
<td>0.9</td>
<td>0/5</td>
<td>1.0</td>
<td>0/5</td>
</tr>
</tbody>
</table>

### Table 3 Pitting probability under MgCl\(_2\) solution films for \( X_d \) values of 1.6, 9.5, and 10 mm.

<table>
<thead>
<tr>
<th>( X_d ) (mm)</th>
<th>35%RH ([\text{Cl}^-]=9.5 \text{ M})</th>
<th>45%RH ([\text{Cl}^-]=8.5 \text{ M})</th>
<th>55%RH ([\text{Cl}^-]=7.4 \text{ M})</th>
<th>65%RH ([\text{Cl}^-]=6.2 \text{ M})</th>
<th>75%RH ([\text{Cl}^-]=4.9 \text{ M})</th>
<th>85%RH ([\text{Cl}^-]=3.0 \text{ M})</th>
</tr>
</thead>
<tbody>
<tr>
<td>( X_t ) (µm)</td>
<td>( N_{pit} / N_{total} )</td>
<td>( X_t ) (µm)</td>
<td>( N_{pit} / N_{total} )</td>
<td>( X_t ) (µm)</td>
<td>( N_{pit} / N_{total} )</td>
<td>( X_t ) (µm)</td>
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<td>1.6</td>
<td>170</td>
<td>5/5</td>
<td>36</td>
<td>5/5</td>
<td>42</td>
<td>0/5</td>
</tr>
<tr>
<td>1.7(^{**})</td>
<td>170</td>
<td>0/5</td>
<td>36</td>
<td>0/5</td>
<td></td>
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<tr>
<td>1</td>
<td>17</td>
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<td>18</td>
<td>0/5</td>
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<td>1.7</td>
<td>17</td>
<td>0/5</td>
<td>18</td>
<td>0/5</td>
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<tr>
<td>10</td>
<td>17(^{**})</td>
<td>5/5</td>
<td>1.8</td>
<td>5/5</td>
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</table>

3. **Results and Discussion**

#### 3.1 Pitting corrosion probability

The pitting corrosion tests were performed using MgCl\(_2\) solution films for various combinations of diameter \( X_d \), thickness \( X_t \), and relative humidity (chloride concentration). Results are summarized in Table 2, where \( N_{total} \) is the total number of samples tested under each set of conditions (\( N_{total} = 5 \)), and \( N_{pit} \) is the number of pitting occurrences among them. Equilibrium chloride concentrations in solution films (Fig. 1) amounted to 3, 4.9, 6.2, 7.4, 8.5 and 9.5 M at 85%, 75%, 65%, 55%, 45% and 35% RH, respectively.

Table 2 shows the probability of pitting at various combinations of diameter \( X_d \), thickness \( X_t \), and \( \text{pH} \) of the droplets. Pitting corrosion occurred at 75% RH \( ([\text{Cl}^-] = 4.9 \text{ M}) \) but not at 85% RH \( ([\text{Cl}^-] = 3.0 \text{ M}) \) regardless of \( X_d \) and \( X_t \). This is in good agreement with previous studies\(^{1,2}\) stating that the critical RH \( \text{crit} \) and \( [\text{Cl}^-] \text{crit} \) for the pitting corrosion of SS430 corresponded to 80% and 4.5 M, respectively. Moreover, there is a tendency that the probability becomes lower as \( X_d \) decreases. Below 75% RH, pits were formed under solution films presenting \( X_d \) values exceeding 1.9 mm, although a low probability. No pit was detected when \( X_d < 1.5 \text{ mm} \), even under quasi-saturated chloride solutions, suggesting that the critical diameter for pitting occurrence lies between 1.5 and 1.9 mm. However, this critical value may also depend on thickness of the solution film.
may enhance pitting corrosion in their experiment. Although differences in dimension and distribution of MnS inclusions were not clear, they may also affect the critical size of solution films.

3.2 Polarization behaviour of SS430 in concentrated chloride solutions

As shown in Fig. 1, stainless steel surfaces exposed to marine atmospheres are covered with highly concentrated chloride solution films. To gain a deeper understanding of their polarization behaviour in such chloride solutions (1–10 M), the cathodic and anodic polarizations of SS430 were investigated in 0.5–2.5 M MgCl₂ ([Cl⁻] = 1–5 M). Solutions above 6 M could not be used because pitting corrosion started immediately after immersion.

3.2.1 Cathodic polarization

The cathodic polarization curves of an SS430 electrode covered with concentrated chloride solution films presenting thicknesses of 10–100 µm ([Cl⁻] = 1–5 M) were determined. A distinct Tafel region showing a slope of about 0.170 V appeared between the corrosion potential \( E_{corr} \) and ca. −0.4 V (Fig. 4). In this potential range, the oxygen reduction reaction (ORR) will be controlled by a charge transfer step. A limiting current region was observed between −0.4 and −0.85 V, where ORR depends on O₂ diffusion through the solution film. Below −0.85 V, the current increased again as a result of the onset of H₂O reduction.

Figure 5 shows the current densities at −0.6 and −0.2 V vs. SSE with respect to the reciprocal film thickness \( X_t^{-1} \). The diffusion limiting current density \( i_d \) at −0.6 V was inversely proportional to the solution film thickness between 20 and 100 µm. The extrapolation of \( X_t^{-1} \) to zero gave an \( i_d \) value of ca. 20 µA/cm², similar to that in a bulk solution of the same chloride concentration (Fig. 6). When \( X_t < 20 \) µm, \( i_d \) remained constant because under very thin solution films, ORR will be controlled by O₂ transport at the air–solution film interface. The current density is expected to be independent of film thickness if ORR is rate-determined by charge transfer. Changes in film thickness affected the current density at −0.2 V to a small extent compared with the diffusion limiting region. This current density decreased slightly with thinning solution film, which may be attributed to a pH increase upon cathodic polarization, and it should be especially significant under thinner films. Changes in the solution chemistry are inevitable during polarization measurements involving thin electrolytes. A detailed analysis of polarization curves measured under thin solution films may
be difficult but thickness-dependent trends can be understood.

Figure 6 shows the cathodic polarization curves of SS430 measured in 0.5–5 M chloride solutions to clarify the effect of chloride concentration, and thus RH. These curves were recorded in bulk solutions to avoid pH changes during cathodic polarization. ORR currents in charge transfer and diffusion limiting potential regions in 0.5 M chloride exceeded those in higher concentration solutions. In general, oxygen solubility decreases with increasing chloride concentration. The suppression of ORR is attributed to a decrease in oxygen concentration. However, the charge transfer current between 2 and 5 M chloride appeared constant, whereas, as expected, the diffusion current decreased when the chloride concentration increased to 4 M before levelling out. These discrepancies suggest that oxygen solubility may be the same within this chloride concentration range, and the reduction of the diffusion current may result from the suppression of oxygen diffusivity in chloride-concentrated solutions. A previous report has shown that the viscosity of solutions increased with increasing chloride concentration.

3.2.2 Anodic polarization

Anodic polarization curves of SS430 were measured in 1–5 M chloride bulk solutions to determine the effect of chloride concentration on the passive current density \(i_{pass}\). These curves were recorded at 10 mV/s after 20 h immersion. At 5 M, pitting corrosion started under the thin solution films (Table 1). SS430 also exhibited pitting corrosion in bulk solutions of 5 M under long-term exposure. The anodic polarization curve was measured before the pitting corrosion onset for 5 M chloride. Above 6 M, the polarization curves were indeterminate because the incubation time for the pitting corrosion onset was too short. Results obtained from triplicate measurements are shown in Fig. 7 for 2 and 5 M chloride solutions. This data showed that \(i_{pass}\) was quite reproducible. A plot of \(i_{pass}\) as a function of chloride concentration (Fig. 8) showed that \(i_{pass}\) decreased gradually when the chloride concentration increased to 4 M before increasing abruptly to 5 M. Because \(i_{pass}\) acts as an index of stability of passive films, its steep increase between 4 and 5 M chloride is consistent with the results of pitting corrosion test suggesting that the critical chloride concentration for pitting occurrence lies between 3.0 and 4.9 M (Table 2). Figure 9 shows a plot of \(E_{pit}\) with respect to chloride concentration. The \(E_{pit}\) was determined from anodic polarization curves recorded at scan rate of 0.5 mV/s.

Fig. 7 Anodic polarization curves of SS430 in (a) 2 M and (b) 5 M chloride bulk solutions at scan rate of 10 mV/s.

Fig. 8 Plots of passive current density \(i_{pass}\) of SS430 at 0 V in Fig. 7 vs. chloride concentration.

Fig. 9 Pitting potential \(E_{pit}\) of SS430 measured in bulk chloride solutions of various concentrations. The \(E_{pit}\) was determined from anodic polarization curves recorded at scan rate of 0.5 mV/s.
3.3 Size effect of solution films on pitting occurrence

Before discussing size effects, RH (chloride concentration) effect is considered using Evans diagrams. The chloride concentration slightly affected ORR current and \( i_{\text{pass}} \) before the onset of pitting corrosion (Figs. 6 and 8). In contrast, the pitting potential \( E_{\text{pit}} \) shifted linearly toward negative potentials with increasing chloride concentration (Fig. 9). The Evans diagram shown in Fig. 10 justifies the critical chloride concentration (or RH) for pitting occurrence. Relative humidity (or chloride concentration)-induced changes in \( E_{\text{corr}} \) are expected to be small because anodic and cathodic reactions do not depend significantly on chloride concentration. On the other hand, \( E_{\text{pit}} \) shifted to negative values when RH decreased or chloride concentration increased. When RH was reduced from 85% to 75%, \( E_{\text{pit}} \) approached \( E_{\text{corr}} \) and pitting corrosion started.

The pitting corrosion probability decreased when solution film diameter and thickness decreased (Table 2). For a diameter of 1.3–1.5 mm and thickness of 0.8–3.2 µm, no pitting corrosion was observed, irrespective of RH. Figure 11 schematically shows the effects of thickness and diameter on pitting occurrence at 35% RH. For \( X_d = 1.6 \) mm, pitting corrosion did not occur for \( X_t = 1.7 \) µm (case I, Table 3) but was visible under a ten times thicker solution film (\( X_t = 17 \) µm, case II, Table 3). An additional pitting corrosion test was conducted using a solution film (case III, Table 3) displaying the same thickness as in case I but a diameter of 10 mm. This test indicated that pitting corrosion occurs with 100% probability (\( N_{\text{pit}} = 5, N_{\text{total}} = 5 \)) under a chloride solution film when an \( X_d \) value of 10 mm is combined with an \( X_t \) value of 1.7 µm. Consequently, pitting corrosion occurs when either thickness or diameter is about 6–10 times larger than that in case I. Let us discuss the differences in pitting occurrence among these cases.

Figure 12 shows Evans diagrams used to explain the onset of pitting corrosion for cases I–III (Fig. 11). When the diameter is fixed (\( X_d = 1.6 \) mm) and the thickness changes (cases I and II), the cathodic current \( i_{\text{ORR}} \) does not change in the potential range of down to approximately −0.4 V because ORR is controlled by the charge transfer (Fig. 4). The passive current density \( i_{\text{pass}} \) is also supposed to be independent of thickness at the same RH (chloride concentration). The thickness effect on \( E_{\text{pit}} \) is rather difficult to determine under thin solution films because solution chemistry rapidly changes upon anodic polarization. If \( E_{\text{pit}} \) does not depend on thickness under thin solution films at constant RH, both anodic and cathodic polarization curves should be similar for cases I and II (Fig. 12). If pitting corrosion occurs in case II, it should also occur in case I. Therefore, pits may nucleate but their growth may be strongly reduced because anodic dissolution of constituent metals from these nuclei is suppressed under the 1.7-µm-thick solution film. A previous report has suggested that the anodic dissolution rate of carbon steel is highly reduced when solution film thickness decreases below several tens of micrometres.

Diameter effects on pitting occurrence are addressed by comparing cases I and III, where the thickness is the same.
The pitting corrosion probability of SS430 under MgCl₂ solution films was investigated for thicknesses ranging between 1 and 70 µm and diameters of 1 to 13 mm. The following conclusions were drawn.

1. When the relative humidity exceeds 85%, no pitting corrosion occurs under solution films regardless of thickness and diameter.

2. The pitting corrosion probability decreases when the solution film diameter and thickness decrease. No pitting corrosion occurred when the solution film diameter was approximately 1 mm, irrespective of solution film thickness and RH.

3. A decrease in solution film thickness is supposed to suppress the anodic dissolution from nucleated pits, and a decrease in diameter is expected to reduce the effective cathodic area for pit growth.

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