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Corrosion Mechanism of Stainless Steel Pipes in Contact with PVC-Coated Support Fittings

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Abstract

The corrosion behavior of SUS304 stainless steel in acidic chloride solutions containing calcium (Ca) or zinc (Zn) ions was investigated by immersion tests, anodic polarization measurements, and scanning electron microscopy (SEM) observations. Test solutions with pH values of 1.5, 2.0, and 3.0 were prepared to simulate acidic environments generated by polyvinyl chloride leachates. The immersion tests revealed that the corrosion potential in the Ca-containing and Zn-containing solutions was lower than that in the solution containing neither Ca nor Zn, particularly at pH 1.5. SEM observations showed distinct differences in surface morphology between the Ca- and Zn-containing conditions and the condition without Ca or Zn, indicating more extensive corrosion in the presence of Ca and Zn. Anodic polarization measurements demonstrated that the passive region was narrower in the Ca- and Zn-containing solutions and that the pitting potential shifted toward lower values. Furthermore, spike-like fluctuations in the passive current density were observed in the passive region, and these fluctuations became more pronounced with increasing pH. Comparison of the corrosion potentials obtained from the immersion tests and polarization measurements indicated that, under most conditions, the corrosion potential was located within the potential interval in which passive-film instability was observed. These results suggest that the presence of Ca or Zn destabilized the passive film on stainless steel and promoted corrosion, even at pH 3.0, where stainless steel would normally be expected to remain passive. It is proposed that the formation of unstable Ca- or Zn-containing surface films, possibly associated with chromium consumption from the passive film, may have contributed to the deterioration of corrosion resistance.

No significant differences were observed between the effects of Ca and Zn under the conditions investigated.

Keywords

Stainless Steel, Corrosion, Chloride, Hot Water Supply Systems

1. Introduction

In hot-water supply systems used in buildings in Japan, stainless-steel pipes are commonly supported by resin-coated dip-type support fittings, in which polyvinyl chloride (PVC) is frequently used as the coating material. Corrosion has been reported in stainless-steel pipes in contact with these dip-coated support fittings, particularly in high-temperature environments exceeding 60˚C, which are often adopted for Legionella control. Such corrosion has also been reported in environments with high ambient relative humidity [1]-[3]. This corrosion is considered a form of localized corrosion caused by the leaching of components, such as hydrogen chloride, from the coating resin of the support fittings [4] [5]. Furthermore, stress corrosion cracking (SCC) is believed to be initiated at these corroded sites and subsequently propagates under the influence of residual stresses in the pipes.

We previously investigated the corrosion of the external surface of stainless-steel pipes caused by components leached from dip-coated support fittings, as well as the occurrence of corrosion sites that can act as crack initiation sites when coating resins with different levels of thermal resistance [6]-[9]. The results showed that the corrosion of the stainless-steel pipes was promoted by chloride ions leached from the coating resin of the support fittings. We also investigated the effect of pH on the surface corrosion behavior of stainless steel [10].

In addition, calcium- and zinc-containing species released from coating resins have been reported to reduce the corrosion resistance of stainless-steel pipes [11] [12]. However, the effects of calcium and zinc ions on the corrosion behavior of stainless steel under acidic conditions remain unclear.

In this study, the effects of pH and the presence of calcium and zinc ions on external surface corrosion of stainless-steel pipes were investigated. Particular attention was paid to the corrosion damage, which can serve as an initiation site for SCC.

2. Method

2.1. Material

In this study, SUS304 TPD-L stainless-steel pipes conforming to JIS G 4305 (2021) were used as specimens. The pipes had a length of 100 mm, an outer diameter of 15.88 mm, and a wall thickness of 0.8 mm. Prior to testing, the specimens were degreased with acetone and thoroughly rinsed with deionized water.

2.2. Test Solution

Based on the results of previous PVC leaching tests, the pH of the solution on stainless-steel pipe surfaces was reported to be 2 or lower [10]. Accordingly, test solutions with pH values of 1.5, 2.0, and 3.0 were prepared using hydrochloric acid. To investigate the effects of calcium and zinc ions on corrosion behavior, three types of solutions were employed: a Ca-containing solution, a Zn-containing solution, and a solution containing neither Ca nor Zn. Experiments were conducted at each pH level for all solution chemistries, resulting in nine experimental conditions.

$CaCl_2$ and $ZnCl_2$ were used as the respective sources of calcium and zinc ions, and their concentrations were adjusted to 300 ppm. NaCl was added to all solutions to achieve a chloride-ion concentration of 1800 ppm. The concentrations of chloride, calcium, and zinc ions were determined based on values reported in a previous study [10].

The Ca-containing and Zn-containing solutions were prepared by mixing 5 mL of a 30,000 ppm $CaCl_2$ or $ZnCl_2$ stock solution, respectively, with HCl and NaCl, followed by the addition of deionized water to a final volume of 500 mL. The solution containing neither Ca nor Zn was prepared in the same manner, except that no $CaCl_2$ or $ZnCl_2$ stock solution was added.

For the pH 1.5 solution, 1.3 mL of 35% HCl was added directly. For the pH 2.0 and pH 3.0 solutions, a pH 1.0 HCl solution was first prepared by diluting 4.2 mL of 35% HCl to 500 mL with deionized water. Subsequently, 50 mL and 5 mL of this pH 1.0 HCl solution were used to prepare the pH 2.0 and pH 3.0 solutions, respectively.

2.3. Corrosion Potential Measurement

A schematic of the test apparatus is shown in **Figure 1**. A 50 mL centrifuge tube was used as the test vessel. The test solution was added to obtain a final volume of 25 mL and stirred at 300 rpm at room temperature. This test was conducted under open-air conditions to evaluate changes in the corrosion potential of a stainless - steel pipe in the test environment. The pipe ends were sealed with a silicone stopper to prevent ingress of the test solution, and measurements were performed on the external surface of the pipe. The immersion period was set to 14 days, and the corrosion potential was measured over time. The corrosion potentials were measured using a digital multimeter (Keysight 34070 A). A saturated Ag/AgCl (SSE) reference electrode was used. The test area measured 3 cm^2. All measurements were performed in triplicate. After testing, the surfaces of the specimens were examined using a scanning electron microscope (SEM; JEOL JSM-IT810).

2.4. Anodic Polarization Curve Measurement

A schematic of the test apparatus is shown in **Figure 2**. A 500 mL beaker was used as the test vessel. The test solutions were prepared in a total volume of 500 mL. All measurements were conducted under open-air conditions at room temperature. Polarization curves were obtained using a potentiostat (Meiden Hokuto: HZ-

5000) at a scan rate of 20 mV min^{-1}. A stainless-steel pipe served as the working electrode, an Ag/AgCl (saturated KCl) electrode (SSE) was used as the reference electrode, and a Pt electrode was used as the counter electrode. The pipe ends were sealed with a silicone stopper to prevent ingress of the test solution, and measurements were performed on the external surface of the pipe. The area of each exposed electrode was fixed at 1 cm^2. All measurements were performed in triplicate.

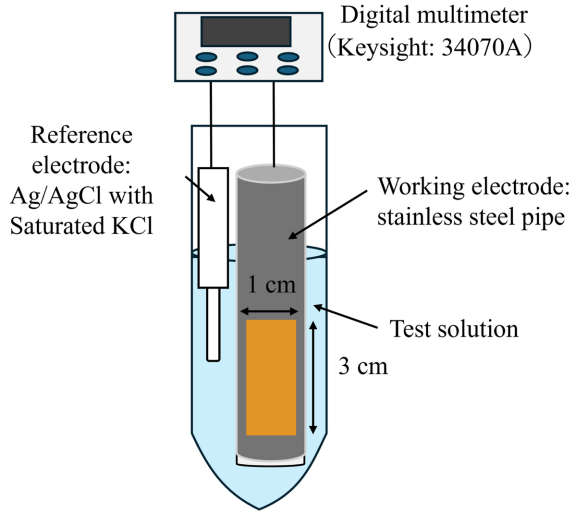


Figure 1. Schematic of the corrosion potential measurement apparatus.

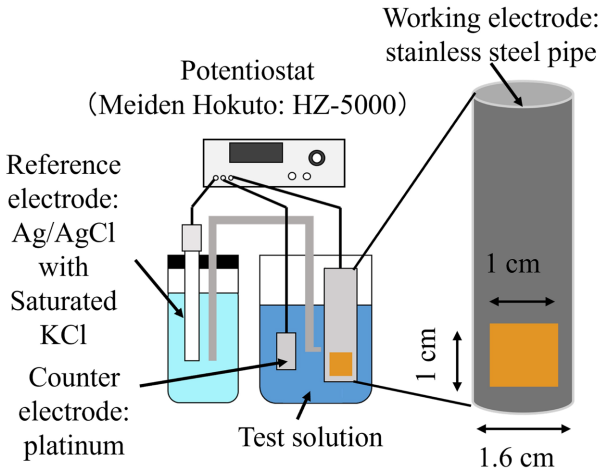


Figure 2. Schematic of the anodic polarization curve measurement apparatus.

3. Results and Discussion

3.1. Corrosion Potential Measurement

The results of the immersion tests are shown in **Figure 3**. Red circles represent the Ca-containing solution, blue diamonds represent the Zn-containing solution, and black squares represent the solution containing neither Ca nor Zn. The horizontal

axis indicates time, whereas the vertical axis indicates the corrosion potential. From left to right, the figures correspond to pH values of 1.5, 2.0, and 3.0. Each data point represents the average of three independent measurements. The largest variation was observed for the Ca-containing solution at pH 3.0, with a pitting potential of 0.381 ± 0.041 V (n = 3, range: 0.344 - 0.425 V).

Under both the Ca- and Zn-containing conditions, the corrosion potential increased immediately after the start of the test at pH 1.5 and 2.0 and subsequently stabilized at approximately 0.30 V in both cases. The corrosion potential under both Ca- and Zn-containing conditions was lower than that under conditions without Ca or Zn, with the difference being particularly pronounced at a pH of 1.5. At pH 3.0, the corrosion potential remained nearly constant at approximately 0.28 V from the beginning of the test under both the Ca-containing and Zn-containing conditions. Furthermore, regardless of the solution composition, the corrosion potential eventually stabilized at a value close to 0.28 V.

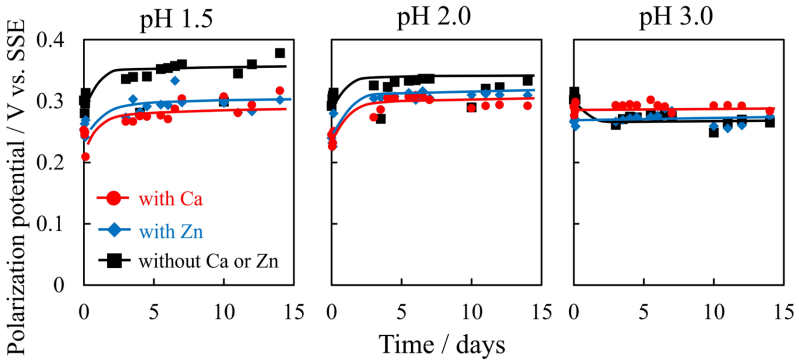


Figure 3. Temporal variation of the polarization potential in the Ca-containing solution (red circles), Zn-containing solution (blue diamonds) and solution containing neither Ca nor Zn (black squares) at pH 1.5, 2.0, and 3.0.

Figures 4-6 show the SEM images of the stainless-steel surfaces before and after the immersion tests in the Ca-containing solution, Zn-containing solution, and solution containing neither Ca nor Zn at pH 1.5 and 3.0.

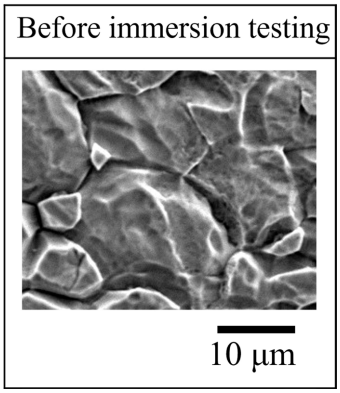


Figure 4. SEM images of the pipe specimen surface before immersion testing. The SEM image has been reproduced from reference 10.

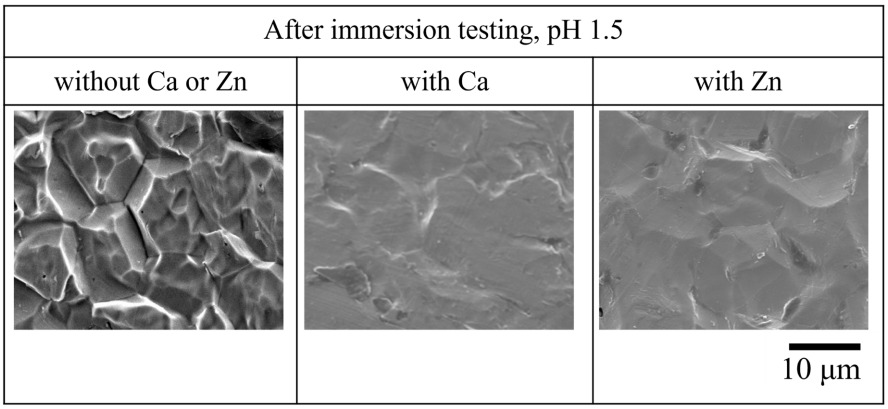


Figure 5. SEM images of the pipe specimen surface after immersion in the Ca-containing solution, Zn-containing solution, and solution containing neither Ca nor Zn at pH 1.5. The SEM image of the specimen immersed in the solution containing neither Ca nor Zn has been reproduced from [10].

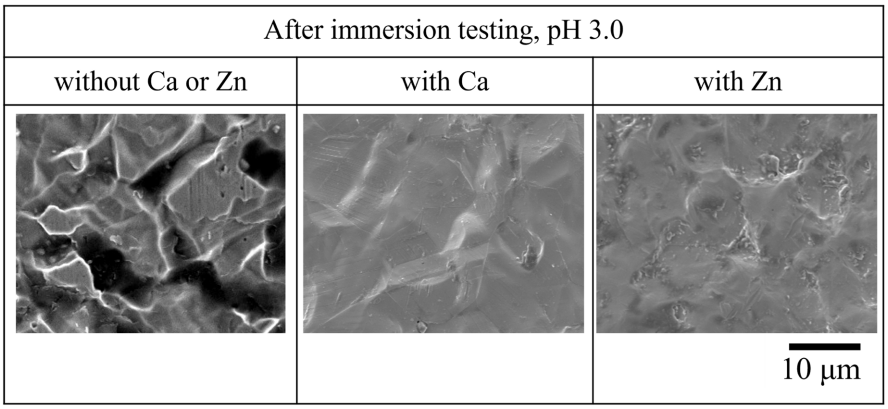


Figure 6. SEM images of the pipe specimen surface after immersion in the Ca-containing solution, Zn-containing solution, and solution containing neither Ca nor Zn at pH 3.0. The SEM image of the specimen immersed in the solution containing neither Ca nor Zn has been reproduced from [10].

Although no obvious corrosion products were observed on the specimen surfaces after the immersion tests under any condition, the SEM observations revealed differences in the surface morphology. At both pH 1.5 and 3.0, the surfaces exposed to the Ca- and Zn-containing solutions exhibited greater surface deterioration than those exposed to the solution containing neither Ca nor Zn, suggesting that corrosion progressed more uniformly over the entire surface under both Ca- and Zn-containing conditions.

3.2. Anodic Polarization Curve Measurement

Figure 7 shows the anodic polarization curves obtained under various conditions. The horizontal axis represents the anodic polarization potential, and the vertical axis represents the current density. From left to right, the figures correspond to pH values of 1.5, 2.0, and 3.0. In the Ca- and Zn-containing solutions, the current density increased sharply at a potential of approximately 0 V and remained nearly

constant up to approximately 0.35 V. Anodic polarization measurements were performed three times under each condition, and the average values are presented in the figure.

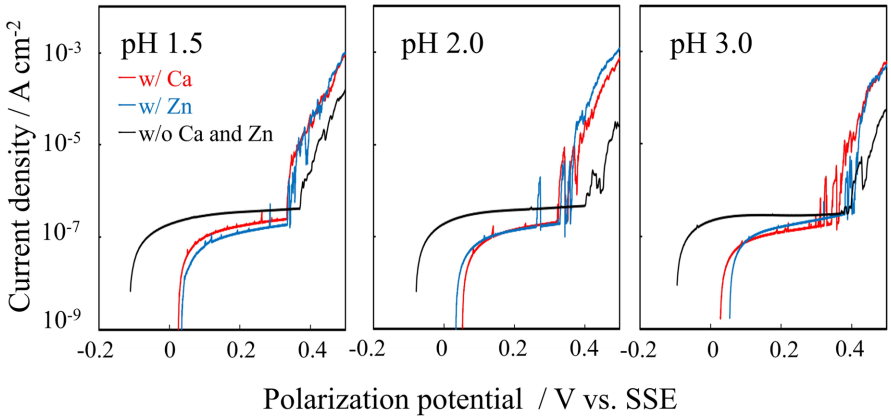


Figure 7. Anodic polarization curves of the pipe specimens in the Ca-containing solution, Zn-containing solution, and solution containing neither Ca nor Zn at pH 1.5 (left), 2.0 (center), and 3.0 (right).

A passivation region, in which the increase in current density was suppressed despite an increase the potential, was observed under all conditions. The passivation region was narrower in the Ca- and Zn-containing solutions than in the solution containing neither Ca nor Zn.

Furthermore, the pitting potential, at which the current density increased again following passivation shifted toward lower values in the presence of Ca or Zn.

Regarding the effect of pH, spike-like fluctuations in current density were observed within the passivation region under both Ca- and Zn-containing conditions. These fluctuations became more pronounced as the pH increase.

Consistent with the immersion test results, qualitatively similar responses were observed between the Ca- and Zn-containing conditions.

3.3. Discussion

Based on the SEM observations, the corrosion behaviors under Ca- and Zn-containing conditions differed from that under conditions without Ca or Zn. Possible reasons for this difference are discussed below.

In general, the passive film on stainless steel becomes unstable at pH values below approximately 2, resulting in increased susceptibility to corrosion. However, the present results suggest that the presence of Ca or Zn may promote corrosion, even at pH 3.0, at which stainless steel would normally be expected to maintain its passive state.

One possible explanation is that Ca and Zn may react with chromium species in the passive film to form chromate compounds such as $CaCrO_4$ and $ZnCrO_4$. The consumption of chromium associated with these reactions may reduce the chromium concentration at the stainless-steel surface, thereby hindering the for-

mation and maintenance of the protective chromium-rich passive film and leading to a deterioration in corrosion resistance.

Figure 8 compares the corrosion potentials obtained from the immersion tests with the pitting potentials determined from anodic polarization measurements. The horizontal axis represents pH, and the vertical axis represents potential. In the figure, circles denote the corrosion potentials, and squares denote the pitting potentials. Because spike-like current fluctuations were observed within the passive region in the Ca- and Zn-containing solutions, the corresponding potential ranges are indicated by double-headed arrows. The corrosion potential was measured three times under each condition, and the error bars represent the maximum and minimum values obtained from these measurements.

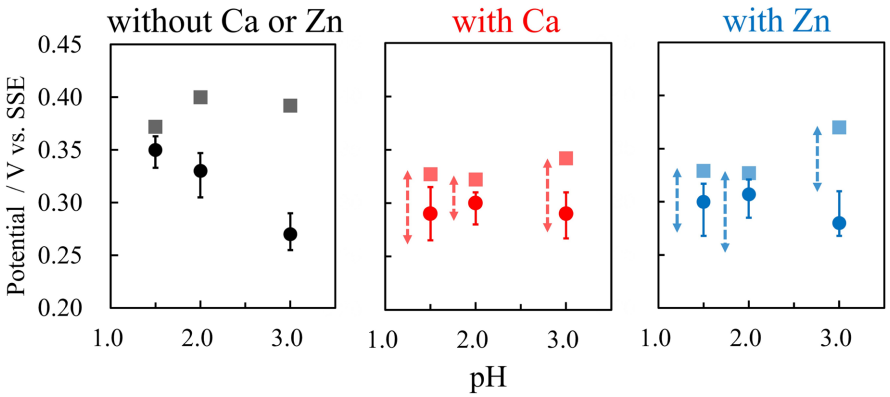


Figure 8. Comparison of corrosion potentials and pitting potentials for the solution containing neither Ca nor Zn (left), the Ca-containing solution (center), and the Zn-containing solution (right). Circles denote corrosion potentials, squares denote pitting potentials, and double-headed arrows indicate the potential intervals over which spike-like fluctuations were observed in the passive region at pH 1.5, 2.0, and 3.0. Error bars indicate the maximum and minimum corrosion potentials obtained from three independent measurements (n = 3).

Under all conditions, the corrosion potential was lower than the pitting potential. However, in the Ca- and Zn-containing solutions, the corrosion potential fell within the potential ranges in which spike-like current fluctuations were observed in the passive region under most conditions. In this study, current-density fluctuations with amplitudes exceeding 6×10^{-8} A cm^{-2} were defined as spike-like fluctuations and were counted as spikes.

These results suggest that the stainless-steel surface may have been exposed to electrochemical conditions associated with passive-film instability during the immersion tests in the Ca- and Zn-containing solutions. Because the passive film is considered to be unstable within the potential range where these spike-like fluctuations are observed, it is proposed that corrosion progressed more readily in this region.

At pH 1.5, it is proposed that, after the original passive film on the stainless-steel surface had been removed, the formation of an unstable film containing Ca

or Zn may have promoted the anodic reaction, thereby accelerating corrosion. This interpretation is supported by the decrease in corrosion potential observed during the immersion tests at pH 1.5.

In contrast, at pH 3.0, it is possible that corrosion resistance deteriorated because an unstable Ca- or Zn-containing film formed heterogeneously on the surface in addition to the original passive film. This interpretation is also supported by the anodic polarization results, in which spike-like fluctuations in the passive current density became more pronounced with increasing pH, suggesting reduced passive-film stability.

The absence of a decrease in corrosion potential at pH 3.0 may be explained by the incomplete removal of the original passive film from the stainless-steel surface. Consequently, the corrosion reaction may not have progressed to the same extent as that at pH 1.5.

Based on these observations, it is hypothesized that Ca and Zn ions leached from pipe-support materials may adversely affect the stability of the passive film on stainless steel and could contribute to leakage failures in stainless-steel piping systems.

4. Conclusions

We investigated the effects of Ca and Zn ions at pH 1.5, 2.0, and 3.0 on the occurrence of external corrosion in stainless steel pipes used in hot-water supply systems. Corrosion potential measurements showed that the corrosion potential decreased in the presence of Ca or Zn ions at pH 1.5 and 2.0. In addition, SEM observations of the specimen surfaces after testing revealed differences in surface morphology among specimens immersed in the Ca-containing solution, Zn-containing solution and solution containing neither Ca nor Zn, suggesting that these ions influenced the corrosion behavior of stainless steel.

Anodic polarization measurements indicated that the passive region became narrower in the Ca- and Zn-containing solutions. Furthermore, spike-like fluctuations in the current density were observed within the passive region under both Ca- and Zn-containing conditions, indicating reduced passive film stability.

Overall, the results suggest that the presence of Ca or Zn ions may have promoted corrosion on the surfaces of the stainless-steel pipe specimens at pH values of 1.5, 2.0, and 3.0.

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Author Contributions

Conceptualization, S.N. and Y.Y.; methodology, K.N., T.T, and T.M; validation, Y.Y., and O.S.; formal analysis, K.N.; investigation, K.N.; resources, K.T. and K.H.; data curation, K.N. and R.T.; writing—original draft preparation, S.N.; writing—review and editing, K.N.; visualization, K.N.; supervision, O.S. and M. I.; project

administration, K.T. and K.H.; funding acquisition, K.T. and K.H. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Koide, M., and Fujita, J. (2009) Surveillance and Prevention of Nosocomial Legionellosis. *Japanese Journal of Infection Prevention and Control*, **24**, 1-8. (In Japanese)

[2] Nakamura, A., Shimazaki, N., Tanaka, R. and Iida, H. (2019) Legionella Contamination in the Water-Supply System of a Hospital and Disinfection Measures after the Outbreak of Hospital-Acquired Legionella Pneumonia. *Japanese Journal of Infection Prevention and Control*, **33**, 193-202. (In Japanese)
https://doi.org/10.4058/jsei.33.193

[3] Murata, K. and Nakajima, H. (2019) Chloride-Induced Stress Corrosion Cracking of Stainless Steel Pipes Caused by PVC Support Materials in Building Services. *Proceedings of Japan Society of Corrosion Engineering Materials and Environments* 2019, Saitama, 21-23 May 2019, 95-98. (In Japanese)

[4] Shigemoto, N., Shibayama, M., Noguchi, S. and Takagi, T. (2004) Cause Analysis of SCC Incident and Observation of PVC Tape Transformation on Heated Steels. *Journal of the Society of Materials Science, Japan*, **53**, 129-135. (In Japanese)
https://doi.org/10.2472/jsms.53.129

[5] Shibayama, M., Takagi, T., Hirano, S. and Shigemoto, N. (2004) PVC Tape Induced Stress Corrosion Cracking Test and Estimation of Cracking Potential of Every Pipes. *Journal of the Society of Materials Science, Japan*, **53**, 136-142. (In Japanese)
https://doi.org/10.2472/jsms.53.136

[6] Hosoya, K., and Takada, K. (2024). Corrosion of Stainless Steel Pipes Induced by PVC‐Coated Support Fittings (DEP-Type Supports). *Proceedings of Japan Society of Corrosion Engineering Materials and Environments 2024*, C-101, 222-225. (In Japanese)

[7] Matsumoto, T., Takahashi, F., Takada, K., Hosoya, K., Yamada, Y., and Sakurada, O. (2025) Corrosion Behavior at the Contact Interface Between Hot-Water Stainless Steel Pipes and PVC‐Coated Support Fittings. *Proceedings of Japan Society of Corrosion Engineering Materials and Environments* 2025, Tokyo, 3-5 June 2025, 265-266. (In Japanese)

[8] Takada, K., Hosoya, K., Matsumoto, T., Takahashi. F., Yamada, Y., and Sakurada, O. (2025) Study on the Corrosion Mechanism of Stainless Steel Pipes by PVC-Coated Support Fittings Part 1 Corrosion Cases and Preliminary Experimental Results. *Proceedings of the Conference of the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan*, Takamatsu, 3-5 September 2025, 85-88. (In Japanese)

[9] Matsumoto, T., Takahashi. F., Yamada. Y., Sakurada. O., Takada. K., and Hosoya. K. (2025) A Study on the Corrosion Mechanism of Stainless Steel Pipes by PVC-Coated Support Fittings Part 2 Effect of Resins with Different Heat-Resistance Temperatures on Corrosion. *Proceedings of the Conference of the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan*, Takamatsu, 3-5 September 2025, 89-92. (In Japanese)

[10] Nishida, S., Nishida, K., Takenaka, T., Matsumoto, T., Yamada, Y., Sakurada, O., *et al.* (2026) Effect of pH on External Surface Corrosion of Stainless Steel Pipes for Hot

Water Supply Systems. *Open Journal of Composite Materials*, **16**, 119-129. https://doi.org/10.4236/ojcm.2026.164009

[11] Nishino, T. (1963) Reaction between Calcium Carbonate and Chromium(III) Oxide. *The Journal of the Society of Chemical Industry, Japan*, **66**, 314-317. (In Japanese) https://doi.org/10.1246/nikkashi1898.66.3_314

[12] Ro, B. (1958) Surface Pretreatment for Painting on Hot-Dip Galvanized Steel. *Journal of the Surface Finishing Society of Japan*, **9**, 57-61. (In Japanese)