

Rust Prevention Mechanism on Cut Edge of Coated Steel Sheets for Buildings

ENDO Reona*¹ YOSHIDA Masahiro*²

Abstract:

Zinc coated steel sheets play an important role in maintaining appearance and improving the service life of building structures. The effect of the amount of deposited salt on the cut edge corrosion behavior of hot-dip Zn-5%Al coated steel sheets was evaluated using ISO 16539B method (ACTETM) and atmospheric exposure test in this study. In the ACTE test, red rust formed in a short period under low salt deposition conditions, whereas white rust formed and red rust was suppressed under high salt deposition. In the exposure tests, red rust preferentially formed in Chiba and Hokkaido where the amount of salt is small, while the cut edge was entirely covered by white rust in Okinawa where the amount of salt is large. The dependence of the amount of salt deposition on the corrosion behavior was similar between ACTE and exposure tests, and it is suggested that the cut edge corrosion behavior under actual environmental conditions can be predicted by ACTE. Furthermore, the differences in corrosion behavior are attributed to variations in sacrificial protection effectiveness, which are influenced by the thickness of the electrolyte film formed depending on the amount of deposited salt.

1. Introduction

Zinc coated steel sheets, which are produced by coating the surface of steel sheets with zinc or a zinc alloy, are widely used in electrical appliances, building materials, automotive applications, etc. because they possess excellent corrosion resistance^{1,2)}. In particular, since building materials are exposed to outdoor environments for long periods of time, long-term durability to prevent corrosion and deterioration is required in building material applications. Since zinc coated steel sheets used in building components are generally sheared in the process of manufacturing products, it is

known that red rust occurs as a result of exposure of the steel substrate at the cut edge, and at the surface near the edge, the corrosion rate of the coating layer is accelerated by galvanic corrosion, in which the steel acts as a cathode³⁾. Although many studies on cut edge corrosion have been carried out from an early date^{3,4)}, there are almost no examples of detailed investigations of the effect of the amount of deposited salt on cut edge corrosion behavior.

On the other hand, various methods are used to evaluate corrosion. While exposure tests are a highly reliable method for evaluating corrosivity under atmospheric environments, variations in the environmental conditions and the long test period are issues. In recent years, the ACTETM (Accelerated Corrosion Test for Electrical appliances) was developed as an accelerated corrosion test that can reproduce the corrosion behavior in actual environments in a short period^{5,6)}, and has been adopted as an international standard as the ISO 16539B method⁷⁾.

Therefore, in this study, we investigated the effect of the amount of deposited salt on the cut edge corrosion behavior of hot-dip Zn-5%Al alloy coated steel sheets using the ACTE test method. To compare the corrosion behavior under actual environments, atmospheric exposure tests were also conducted at various locations with different amounts of airborne salts, and the applicability of the ACTE method to actual environments was examined.

2. Experimental Method

2.1 ACTE Test

2.1.1 Test Material

The test material used in this study was hot-dip

[†] Originally published in *JFE GIHO* No. 57 (Feb. 2026), p. 84–88

*¹ Senior Researcher, Coated Products Research Dept., Steel Res. Lab., JFE Steel

*² Manager, Coated Products Research Dept., Steel Res. Lab., JFE Steel

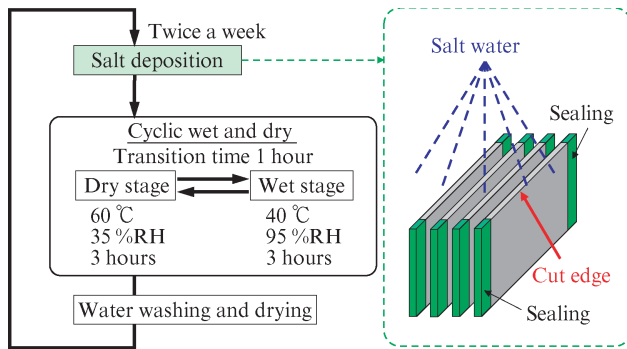


Fig. 1 Test condition of ACTE™

Zn-5%Al alloy coated steel sheets with a sheet thickness of 1.6 mm and a coating weight per side of 90 g/m². A chromate-free treatment layer was applied to the sheet surface. For use in the test, the material was sheared to a size of 70 mm × 30 mm, and the short sides, including the cut edge surfaces, were sealed with tape. The evaluation surface was the edge of the long side (70 mm), and the ratio of the shearing surface and breaking surface at edge was approximately 1 : 1.

2.1.2 Test Conditions and Evaluation Method

The test conditions of the ACTE method used in the corrosion tests are shown in Fig. 1. The ACTE method consists of repeated processes of salt deposition and cyclic wetting and drying. Salt is deposited on the test pieces by spraying salt water with spray equipment. Artificial seawater (Aqua-marine™, manufactured by Yashima Pure Chemicals Co., Ltd.) was used as the salt water. In this test, the change over time in the corrosion of the cut edge of the hot-dip Zn-5%Al alloy coated steel sheets with different amounts of deposited salt was investigated. In conducting the test, the test pieces were set with the cut edge upward, and the amount of deposited salt was adjusted in the range from 10 mg/m² to 3 000 mg/m² by controlling the salt water dilution rate and deposit.

The change over time in cut edge corrosion was evaluated by observation of the appearance of the cut edge surface and the red rust area ratio (ratio of the area of red rust generation to the total area of the cut edge). The red rust area ratio was calculated by photographing digital images of the cut edge and binarizing the red rust area and other areas using a saturation based threshold.

2.2 Atmospheric Exposure Tests

2.2.1 Test Material

As the test material for the atmospheric exposure tests, hot-dip Zn-5%Al alloy coated steel sheets with a thickness of 1.6 mm and coating weight per side of

	①Ginowan, Okinawa	②Tateyama, Chiba	③Tomari, Hokkaido
Exposure test sites			
Annual mean temperature	23 °C	16 °C	9 °C
Annual mean relative humidity	76 %	75 %	75 %
Equivalent salt deposit density (ESDD)	1 200 mg/m ²	200-400 mg/m ²	50-150 mg/m ²

Fig. 2 Environmental conditions for atmospheric corrosion test sites

200 g/m² were used. A chromate-free treatment layer was applied to the material surface. The test pieces for the corrosion test were sheared to a size of 70 mm × 150 mm, and the short sides, including the cut edges, were sealed with tape, leaving an exposed edge with a length of approximately 100 mm of the long edge. The corrosion evaluation was performed using the 70 mm × 100 mm surface and the cut edge of approximately 100 mm that was not sealed with tape. The ratio of the shearing surface and breaking surface at edge was approximately 1 : 1.

2.2.2 Test Conditions and Evaluation Method

The atmospheric exposure tests were conducted near the coast at three sites in Japan (Ginowan in Okinawa Prefecture, Tateyama City in Chiba Prefecture and Tomari Village in Hokkaido). The average environmental conditions⁸⁾ at each site are shown in Fig. 2. Okinawa has a larger amount of deposited salt (equivalent salt deposit density: ESDD) than Hokkaido or Chiba, and is also a high temperature environment. The average values of the relative humidity at the three sites are almost the same. The test pieces were mounted on test racks installed on electric power poles at each site, and were exposed over a 3-year period from November 2020 to November 2023. The corrosion evaluations were conducted by recovering the test pieces at intervals of 1 year and observing the appearance of the cut edges. After observation, the test pieces were installed on the test racks again and observed continuously over the 3-year period.

3. Results and Discussion

3.1 Results of ACTE Test

The effects of the amount of deposited salt and the corrosion period on the appearance of the cut edge are shown in **Fig. 3**. When the amount of deposited salt was 10, 50, 100 or 500 mg/m², red rust occurred on the 7th day accompanying the dissolution of the substrate steel at the breaking edge. By the 28th day, the red rust had spread over the entire breaking surface, and on the 56th day, part of the red rust was covered with white rust, which is considered to be corrosion products of zinc (Zn). Subsequently, no large changes in the condition of the red rust were observed. In contrast, when the amount of deposited salt was 1 000 mg/m² and 3 000 mg/m², almost no occurrence of red rust was observed until the 28th day, and the entire cut edge surface was covered with white rust. However, red rust was confirmed on the 56th day at the breaking edge and gradually increased thereafter.

Figure 4 shows the change over time in the red rust area ratio for each amount of deposited salt condition. As shown in **Fig. 3**, when the amount of deposited salt was 10, 50, 100 or 500 mg/m², the red rust area ratio increased with time up to the 28th day from the start of the test, and then gradually decreased. In the initial period, the corrosion rate showed a tendency to increase as the amount of deposited salt increased, but no significant differences can be seen when the amount of deposited salt is 100 mg/m² or larger. On the other hand, when the amount of deposited salt was 1 000 or 3 000 mg/m², generation of red rust was suppressed until the 28th day, and an increase in the red rust area ratio could be seen after that point. Subsequently, red rust increased with the passage of time, and on the 112th day, the red rust area ratio was higher than in the case of smaller amounts of deposited salt.

When the amount of deposited salt is small, the amount of water film due to moisture absorption by the salt is small, even under high-humidity conditions. For this reason, it is thought that adequate sacrificial protection cannot be obtained by the formation of a galvanic couple with Zn extending to the steel substrate, which is away from the coating, and in this case, the corrosion rate of the coating is small, and the formation of white rust, a corrosion product of Zn with a protective effect, is slight. As a result of these conditions, it is inferred that red rust was generated from the initial period of the test at the breaking surface, where entrainment of the Zn coating, particularly by shearing of the edge surface, is slight. On the other hand, when the amount of deposited salt is large, a wide region of the cut edge surface is covered with an electrolyte liquid

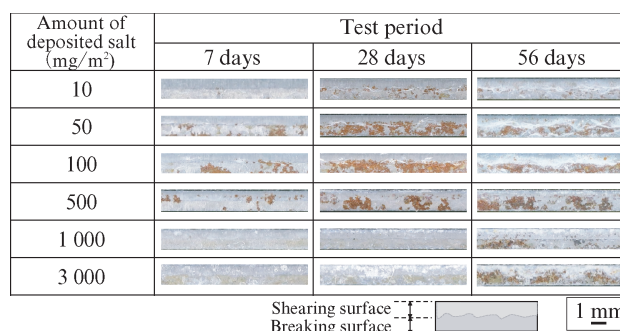


Fig. 3 Cut edge appearance of coated steel sheets in ACTE

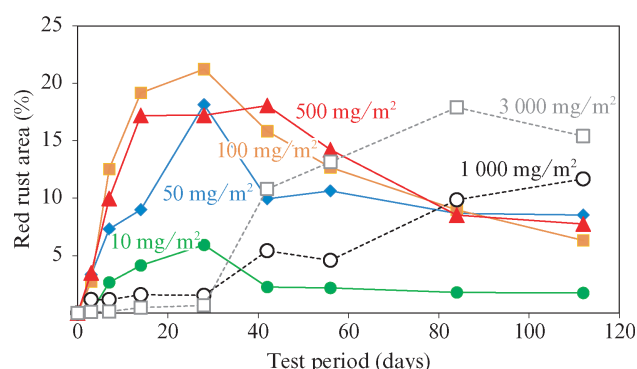


Fig. 4 Time dependence of the red rust area ratio on the edge in ACTE

film due to moisture absorption by the salt, and generation of red rust tends to be suppressed by sacrificial protection by Zn, even in the steel (Fe) substrate, which is away from the coating. In addition, it is thought that the highly concentrated salt accelerates the formation of white rust, and the edge surface is protected by the white rust in the initial stage of corrosion.

3.2 Results of Atmospheric Exposure Test

The appearance of the test pieces exposed in Okinawa, Chiba and Hokkaido are shown in **Fig. 5**. The photographs show the surface on one side and the cut edges on both sides of the test pieces after the passage of 1 year and 3 years. However, since the corrosivity of the cut edges is biased due to the effects of the wind direction, etc., the corrosion behavior will be described focusing on the cut edge where the generation of red rust was particularly notable.

In the test piece exposed in Okinawa, in the 1st year, the entire cut edge surface was covered with white rust, which is considered to be a corrosion product of the Zn coating, and occurrence of red rust was not observed. In the 2nd year, red rust can be confirmed on the cut edge, and in the 3rd year, the red rust has spread over the entire surface of the cut edge, and has also progressed to the general surface of the test piece. In Chiba, in the 1st year, local spots of red rust were

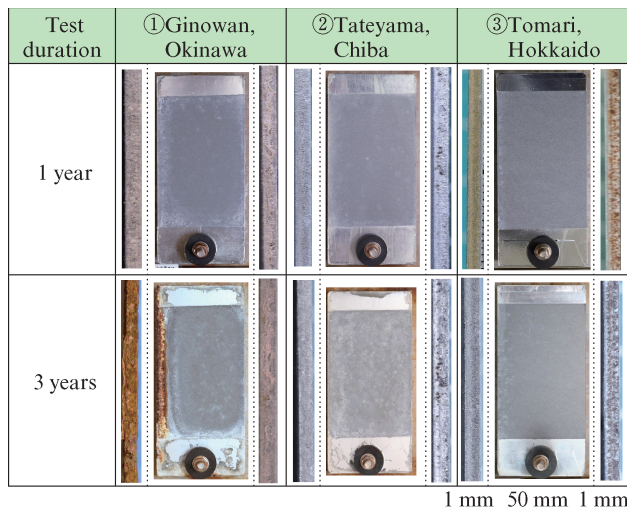


Fig. 5 Appearance of surface and cut edge in exposure tests

observed in the white rust at the cut edge on the right side, and spots of red rust had spread somewhat by the 3rd year. However, looking at the cut edge as a whole, white rust is predominant, and red rust has not spread to a wide region. In Hokkaido, focusing on the cut edge on the right side, a large amount of red rust can be seen in the 1st year, and red rust spread to the entire cut edge in the 2nd year and after; however, in the 3rd year, the amount of white rust increased, and no increase in red rust could be seen. The surface of the test pieces exposed in Chiba and Hokkaido did not display red rust even in the 3rd year. On the other hand, a gradual spread of white rust could be seen from the edge opposite the side where red rust was observed on the cut edge.

These results showed that under environments with a large amount of deposited salt, such as Okinawa, white rust is formed preferentially in the initial stage of corrosion, and generation of red rust is suppressed. This is also consistent with the tendency observed in the ACTE test that white rust covered the cut edge and generation of red rust was delayed under conditions with a large amount of deposited salt (1 000 mg/m² or more). Conversely, under environments with small amounts of deposited salt, such as Chiba and Hokkaido, the results showed that red rust displays a tendency to occur locally in an early stage, after which further growth of the red rust generated in the early stage is suppressed by the formation of white rust covering the cut edge. This tendency is consistent with the tendency in the ACTE test that red rust occurs in a comparatively early stage of the test and shows little increase thereafter under the condition that the amount of deposited salt is small (500 mg/m² or less).

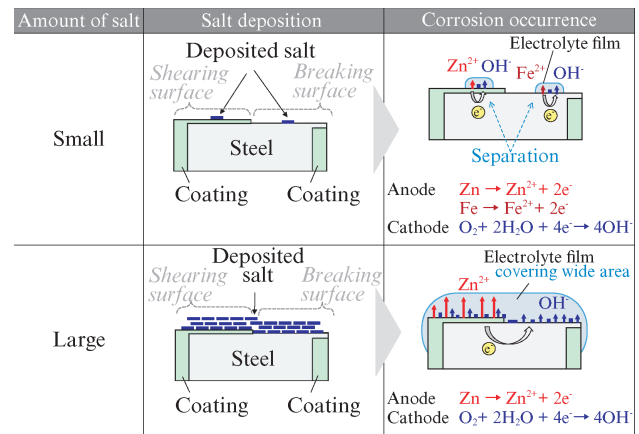


Fig. 6 Estimated mechanism of the cut edge corrosion of coated steel

3.3 Effect of Water Film on Corrosion Behavior of Cut Edge

The results of the ACTE test and atmospheric exposure test clarified the fact that the cut edge corrosion behavior of hot-dip Zn-5%Al alloy coated steel sheets depends on the amount of deposited salt. Furthermore, in the atmospheric exposure tests, it was suggested that corrosion of the cut edge interacts with the effects of corrosion of the general surface. Specifically, it is thought that the electrolyte liquid film formed by the deposited salt causes a short circuit between the surface and cut edge, and the resulting electrochemical reaction determines the corrosion behavior of the material as a whole. Based on these results, **Fig. 6** shows a schematic illustration of the estimated mechanisms of cut edge corrosion depending on differences in the amount of deposited salt. Since the test material used in this research is a hot-dip Zn-5%Al alloy coated steel sheet, in actuality, it is considered that not only Zn and Fe, but also Al dissolve, contributing to the formation of corrosion products. However, for the purposes of this explanation, we will use a simplified model that considers only Fe and Zn as metallic elements.

When the amount of deposited salt is small, it is thought that formed electrolyte liquid film will be thin and cannot fully cover the entire cut edge, even in case where corrosion occurs under high humidity. Under such conditions, sacrificial protection by the formation of a galvanic couple with Zn is limited, and corrosion of the steel part of the cut edge progresses easily, resulting in preferential formation of red rust. On the other hand, when the amount of deposited salt is large, a comparatively thick electrolyte liquid film forms on the cut edge, enabling sacrificial protection by Zn by the formation of a galvanic couple across the entire cut edge surface. As a result, white rust, which is a corrosion product of Zn, is formed from the initial stage at

the start of the test, thereby suppressing corrosion of the steel and the generation of red rust.

It can be inferred that this difference in corrosion behavior is due to a change in the electrochemical conditions originating in the thickness of the formed electrolyte liquid film, corresponding to the amount of deposited salt. In particular, since the sea salt deposited on a metal surface contains multiple salts, such as NaCl, MgCl₂, etc., the electrolyte liquid film is formed by absorption of moisture in the air, corresponding to the relative humidity of the surroundings, by the moisture absorption actions of the various salts. Although moisture absorption by NaCl alone is difficult when the humidity is less than its saturated vapor pressure, sea salt containing MgCl₂ and other salts easily absorbs moisture even at lower humidities, and the thickness of the liquid film tends to increase as the amount of salt becomes larger⁹⁾. In the corrosion reaction, the electrolyte liquid film formed by this process mediates the flow of the electrical current between the anode of the electrochemical reaction (e.g., site where a dissolution reaction of Zn, Fe, etc. occurs) and the cathode (e.g., site where an oxygen reduction reaction or hydrogen evolution reaction occurs on a metal). The ease of the flow of the electrical current through this electrolyte liquid film is determined by the solution resistance R_{sol} , which is expressed by the following equation:

$$R_{sol}=L/(\kappa \cdot S) \dots\dots\dots (1)$$

Where, L is the length of the water film, S is the cross-sectional area of the water film and κ is the electrical conductivity. In cases where the amount of deposited salt is small and a thin liquid film forms, or the continuity of the liquid film is poor, the cross-sectional area S is small, resulting in a large solution resistance R_{sol} , which increases IR-drop. This limits the supply of electrical current from Zn to Fe, which is away from the Zn, and the effective anode area contributing to sacrificial protection decreases. Under this condition, the potential of the Fe is not reduced by Zn, and Fe corrodes at its own corrosion potential, generating red rust. Conversely, when the amount of deposited salt is large and a thick liquid film forms, the cross-sectional area S is large and solution resistance R_{sol} decreases, and as a result, IR-drop also decreases. Therefore, the Fe and Zn deposited on the surface and shearing surface of the cut edge form a short circuit via the electrolyte liquid, making it possible to supply a current across a wide area, which expands the effective anode area contributing to sacrificial protection. Consequently, it is thought that the coupling current is increased, and the potential of the Fe is reduced in the direction approaching the coupling potential with Zn,

thereby suppressing corrosion of the Fe. Based on these points, the difference in cut edge corrosion behavior depending on the amount of deposited salt is considered to originate from a difference in the formation of the electrolyte liquid film corresponding to the amount of deposited salt, and the accompanying difference in sacrificial corrosion protection performance.

4. Conclusion

The effect of the amount of deposited salt on the cut edge corrosion behavior of hot-dip Zn-5%Al alloy coated steel sheets was investigated using the ACTE test and atmospheric exposure tests. The results may be summarized as follows.

- 1) When the amount of deposited salt is small (500 mg/m² or less), red rust is generated on the cut edge in the initial stage of corrosion, and growth of the red rust is then suppressed by the formation of white rust of Zn. However, when the amount of deposited salt is large (1 000 mg/m² or more), white rust covers the cut edge in the initial stage of corrosion, suppressing the generation of red rust. With the passage of time, red rust is generated, and when the red rust spreads on the cut edge, it will progress from the edge to the general surface.
- 2) The results of the ACTE test showed relatively good agreement with the corrosion behavior observed in the atmospheric exposure tests, suggesting that it is possible to predict and evaluate the cut edge corrosion behavior of coated steel sheets in actual environments with different amounts of airborne salts by using the ACTE test.
- 3) It can be inferred that differences in cut edge corrosion behavior depending on the amount of deposited salt are caused by changes in the effective anode area due to differences in IR-drop associated with differences in the thickness of the water film.

The knowledge gained through this research is basic knowledge related to the effects of the amount of deposited salt on the cut edge corrosion behavior of coated steel sheets for buildings, and suggests that corrosion in actual atmospheric environments can be reproduced by accelerated corrosion tests. In the future, the authors hope to further deepen understanding of the corrosion behavior of the cut edge, leading to the development of highly accurate corrosion prediction techniques for the use environments of coated steel sheets for buildings and surface-treated steel sheets with excellent corrosion resistance.

References

- 1) Pelerin, J.; Bramaud, B.; Coutsouradis, D.; Radtke, S. J. Met. Finish. Soc. Jpn. 1882, vol. 33, no. 10, p. 474-488.

- 2) Blirckwedge, D, J. Tetsu-to-Hagané. 1980, vol. 66, no. 7, p. 821–834.
- 3) Matsumoto, M.; Kimoto, M.; Sakoda, A.; Kudou, T. Tetsu-to-Hagané. 2005, vol. 91, no. 9, p. 700–705.
- 4) Sekine, K.; Hatayama, K. Rust Prev. Control. 1986, vol. 30, p. 101–108.
- 5) Kajiyama, H.; Fujita, S.; Fujii, K.; Sakai, M. Corros. Eng. 2006, vol. 55, no. 8, p. 356–363.
- 6) Kajiyama, H.; Fujita, S.; Sagiya, M. JFE Technical Report. 2007, no. 9, p. 80–86.
- 7) ISO 16539 : 2013. Corrosion of metals and alloys — Accelerated cyclic corrosion tests with exposure to synthetic ocean water salt-deposition process — “Dry” and “wet” conditions at constant absolute humidity.
- 8) Technical Committee on Quantitative Evaluation of Degradation Environment for Distribution Equipment. 2013, vol. 69, no. 3, p. 56–137.
- 9) Oshikawa, W.; Shinohara, T.; Motoda, S. Corros. Eng. 2003, vol. 52, no. 6, p. 293–298.