

Galvanic corrosion behavior between hot-dip 55Al-Zn and Al coatings in the atmospheric environment

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1. Introduction Atmosphere corrosion of steel structure is one of the most critical issues. Hot-dip coatings are of great significance in protecting steel to improve the durability of the structure and reduce their cost¹⁾. Hot-dip coatings are usually used for relatively small size steel members such as bolts, etc., and the majority of the tiny parts can be coated. Until now, the corrosion behavior of Al-based hot-dip coatings have been studied a lot by scholars. Corresponding anti-corrosion effects on steel members were usually clarified according to their microstructural characterization, oxidation kinetics, etc.²⁾. However, when the steel members which coated by different hot-dip coatings contacting directly, the galvanic corrosion would occur between coatings under high risk, especially in the immersion or aggressive atmospheric environment. In this study, the galvanic corrosion behavior of 55Al-Zn and Al coatings in an atmospheric environment was investigated according to the exposure test and electrochemical test.

2. Test method

The specimen is including two components, which are the steel plate with hot-dip Al coating and M16 bolts with hot-dip 55Al-Zn coating. The steel plates (150×70×6mm) were fabricated based on JIS G 3106 SM490A, fixed by M16 bolts at the central position. Atmosphere exposure test was carried out in two sites, and specimens were taken back for the indoor test analysis after two years of exposure. The exposure locations are 1) University of Ryukyu (denoted as UR) with rain washing effect outdoor; 2) Kyoda, located under the viaduct of the city road at about 30 m distance from the west coastline, where has no rain washing effect. The environment data of the exposure sites as shown in Table. 1. All specimens were placed 45° from horizontal so that the rain washing effect on the skyward and groundward portions in one specimen could be compared. Two years of exposed specimens were cut along with the vertical central line, for the cross-sectional observation and element analysis. Besides, the epoxy resin was used for fixation during the cutting process to ensure the integrity of the bolt and steel plate. The photo of the specimen after machining and polishing, as shown in Fig. 1. Since the specimens were inclined positioned during two years of atmospheric exposure, the portions most susceptible to the rainwater accumulation effect were considered as the test targets for the subsequent experiment, which are the skyward and groundward targets. Furthermore, the profile observation and element analysis of these two targets were performed using SEM-EDX, while the element distribution in the depth profile of the contact part between bolt washer (55Al-Zn) and steel plate (Al) was measured in the skyward target of specimen exposed in UR. The total measure range for the elemental concentration analysis are a rectangular area (Length of 320μm, width 25μm), and the test area of each point was also a rectangular area (Length of 21μm, width 17μm) as shown in Fig. 2. The weight percent of element Fe, Al, Si, Zn in each point were obtained with an interval of 5 μm from skyward to groundward direction.

The dimension of electrochemical test specimens is 100×50×5 mm. The substrate also used SM490A and hot-dipped by 55Al-Zn and Al coatings, respectively. Two concentrations of 0.1 mass% and 3.5 mass% of the neutral NaCl solution were prepared, and acted as the electrolyte during the electrochemical test without any external stirring. For the bolt specimen exposed in actual, generally the area of Al coated steel plate should much bigger than that of 55Al-Zn coated bolt components. Therefore, to simulate the actual situation and verify the effect of area ratios on the galvanic behavior, the galvanic currents were measured by changing the area ratio of coatings in the electrochemical test. A pair of specimens coated with 55Al-Zn and Al coatings were short-circuited using a zero resistance ammeter, to measure the continuous dynamic current for 48 hours. By changing the immersed area of Al coating (S_{Al}) and 55Al-Zn coating ($S_{55Al-Zn}$), the area ratio ($S_{Al}/S_{55Al-Zn}$) was controlled to be 1, 2, 3, and 4.

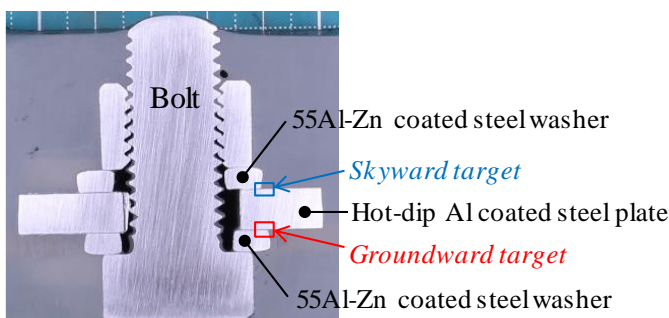


Fig. 1 Cut cross-section of the bolt specimen in the vertical line after surface polishing

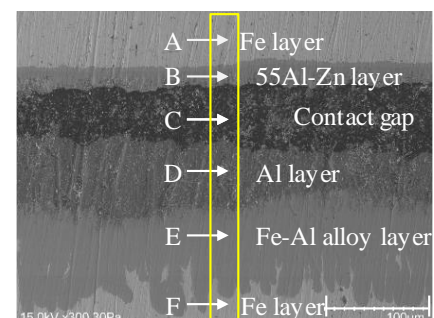


Fig. 2 Measuring area of element concentration analysis in the skyward target (UR)

Keywords: Galvanic corrosion, hot-dip coatings, bolted joints, atmospheric environment, electrochemical test

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Table 1 The Environmental Data of Two Exposure Sites

| Exposure site | Temperature <i>T</i> (°C) | Humidity <i>RH</i> (%) | Flying salt <i>w</i> (mdd) | Offshore distance (m) | Average precipitation (mm/day) | Rain washing effect |
|---------------|------------------------------|---------------------------|-------------------------------|--------------------------|-----------------------------------|------------------------|
| UR | 22.9 | 81.5 | 0.3 | 2300 | 5.2 | Yes |
| Kyoda | 22.7 | 82.9 | 0.5 | 30 | 5.3 | No |

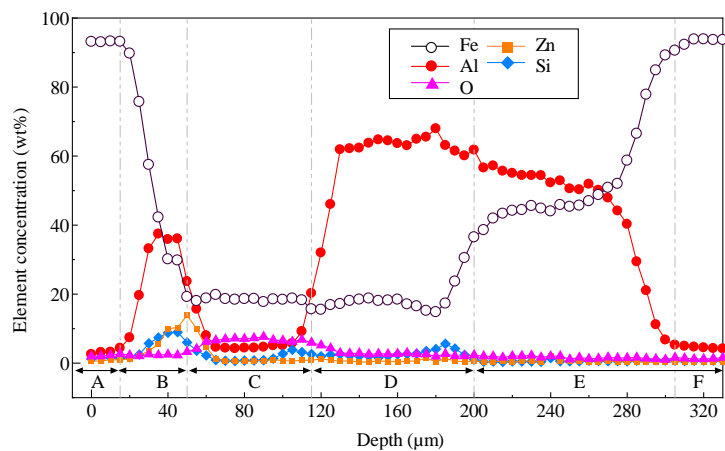


Fig. 3 Depth profiling of the elements constituting the coating (UR)

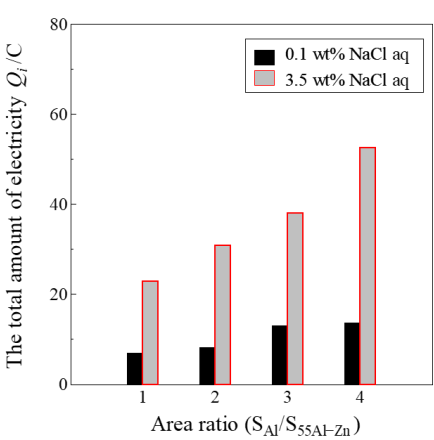


Fig. 4 The total amount of electricity according to different area ratio

Table 2 The Element Analysis by EDX (300 times)

| | UR | | | Kyoda | | |
|------------|----|----|---|-------|----|---|
| | Al | Zn | O | Al | Zn | O |
| Skyward | | | | | | |
| Groundward | | | | | | |

3. Test results The thickness of each coating layer could be identified in Fig.2, and the elemental constituting according to the depth, as shown in Fig. 3. From this graph, we can obtain various elements composition in the thickness direction of each part. Table 2 shows the elemental analysis of specimens by EDX. The results of both sites show that the oxides of skyward were much more than that of groundward. Al and Zn dissolution in the 55Al-Zn coating occurred. Moreover, the Zn dissolve behavior was more severe by comparing the dissolution area. Compare the UR and Kyoda exposure specimens, Kyoda specimen generated more corrosion products and more serious corrosion behavior. It was speculated that more flying salt accumulation occurred in Kyoda as there was no rain washing effect. In a high salt accumulation environment, the 55Al-Zn coating was more easily occurs sacrificial anode reaction and causes the metal dissolved when it contacted with Al coating ³⁾. The Al coating was still intact after two years, even the outermost Al layer also looks complete and no severe dissolution behavior could be detected. In addition, the electrochemical test results as show in Fig. 4. In the case of 0.1 mass% NaCl solution, the increase of total amount of electricity was not evident when the area ratio larger than two. However, in case of 3.5 mass%, the total amount of electricity increases linearly along with the increase of area ratio. It was considered that the environmental chloride concentration would largely affect the galvanic corrosion behavior between 55Al-Zn and Al hot-dip coatings.

4. Summary 1) After two years exposure test, the rain and high salt accumulation parts occurs the galvanic corrosion easily. 2) As the dissolution of Zn was easier occur than Al, galvanic corrosion occurs in the 55Al-Zn coating due to the contact of 55Al-Zn coating and Al coating. Al coating has a better shielding effect for steel protection. 3) The galvanic current increases linearly along with the increasing of area ratio between 55Al-Zn and Al hot-dip coatings, whereas in the low concentration of NaCl solution this phenomenon is not evident.

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