Abstract:

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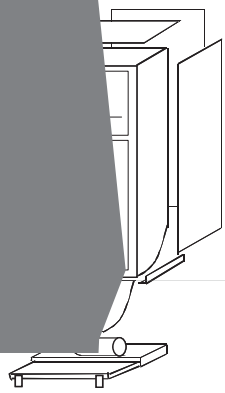


coated steel sheets with chromate-free coatings, JFE Steel and the Hitachi Research Laboratory, Hitachi, Ltd. jointly developed a new accelerated corrosion test method called ACTE (Accelerated Corrosion Test for Electrical Appliances) which has a high correlation with actual environments[19–28]. The new method was developed based on the actual corrosion behavior in Zn-coated steel sheets in electrical appliances and the inadequacies of the conventional accelerated corrosion test methods (SST; JASO M609-91, which is a type of CCT), to enable appropriate selection of Zn-coated steel sheets for electrical appliances, including chromate-free products. Details are described in the following.

2. Actual Corrosion Behavior in Electrical Appliances[19–23,25]

First, electrical appliances (air-conditioner outdoor units, washing machines, and refrigerators) were collected from the Main Island of Okinawa (Okinawa Pref.), Japan's Pacific Ocean coast (City of Choshi, Chiba Pref.), and the Sea of Japan coast (City of Niigata, Niigata Pref.), all of which are regions where salt attack is a problem, and from an inland area (City of Tsukuba, Ibaraki Pref.), where the effect of sea salt is slight, and the corrosion behavior in the Zn-coated steel sheets in these electrical appliances and the effect of the distance from the coast and amount of sea salt deposition were investigated in detail. **Figure 1** shows schematic diagrams of the locations of parts of the recovered electric appliances with high susceptibility to corrosion[19,20]. In the air-conditioner outdoor units (hereafter, referred to simply as air-conditioners), corrosion was observed at the air vents on the side cover and front cover, the upper side of the bottom plate, the edges of steel sheets, etc[19,25]. In the washing machines, corrosion was observed in the painted steel sheets at the edges of the exterior cover panels and around lapped portions, and in the chromate coated steel sheets used in interior parts[20,21]. In contrast to this, in the refrigerators, corrosion was limited to partial red rust at the bottoms of painted steel sheets used in the exterior cover panels in refrigerators with ages of 10 years or more[20]. The corrosion morphologies observed were occurrence of filiform corrosion on painted cold rolled steel sheets in the refrigerators collected from Okinawa and masses of fine paint film swelling in painted Zn-coated steel sheets in the air-conditioners collected from Okinawa[19,23,25]. The latter was a clearly different corrosion morphology from the blister corrosion (water-encapsulating swelling of the paint film) which is observed in the SST and similar tests.

An analysis of the relationship between corrosion of electrical appliances and the distance from the coast/amount of deposited sea salt revealed that, in air-conditioners, corrosion is more severe in air-conditioners sheltered under house eaves with limited exposure to rain in coastal areas, than in units installed in locations exposed to rain, and in inland areas, corrosion is generally slight in comparison with that in coastal areas[19,25]. Focusing on the corrosion of air-conditioners installed in sheltered locations under eaves in coastal areas, devia-

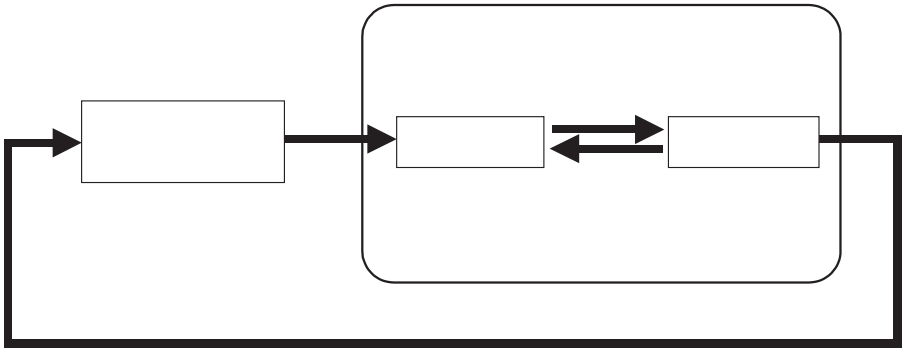
tions were large and the effect of the distance from the coast was unclear. However, as shown in **Fig. 2**, when the results were arranged by the amount of deposited sea salt, it was found that the effect of the amount of salt deposition is large[25]. Similarly, with washing machines, an investigation of the relationship between the corrosion rate of painted steel sheets used in the exterior covers and the amount of deposited sea salt revealed that the amount of salt deposition also affects corrosion in washing machines[20,21]. On the other hand, corrosion was slight in the refrigerators collected from Okinawa Pref. in comparison with the air-conditioners and washing machines. However, it should be noted that the amount of sea salt deposited on the exterior covers of the refrigerators was also small, being less than 1 $mg \cdot m^{-2}$ (ref.19). Based on the above-mentioned results, as a parameter of corrosion in electrical appliances (air-conditioners, washing machines, and refrigerators), the amount of deposited sea salt is considered to have a large effect.

Furthermore, as shown in **Fig. 3**, monitoring of the temperature and relative humidity in the environments where these electrical appliances were used revealed that changes in temperature/relative humidity follow the curve of the dew-point temperature; in other words, temperature and relative humidity changes occur under a condition in which the absolute humidity is substantially constant[23].

3. Development of New Accelerated Corrosion Test Method for Electrical Appliances ACTE [24–28]

3. 1 Features of New ACTE Test Method

Based on the results of the investigation of the corrosion behavior in electrical appliances in actual environments, the fact that the conventional accelerated corrosion test methods (SST; JASO M609-91, which is a type of CCT) have a low correlation with actual environments was confirmed, and a new accelerated corrosion test method, “ACTE,” for Zn-coated steel sheets for electrical appliances which has a high correlation with actual environments was developed. **Figure 4** shows an example of the test conditions of the ACTE[24–28], and **Fig. 5** shows an illustration of the ACTE test method. The ACTE test conditions comprise (1) a process of periodically depositing sea salt containing chloride ions on the surface of the test specimen (salt deposition process) and (2) a repeated process of drying and wetting the test specimen by changing the temperature and relative humidity in an environmental testing device (cyclic wet/dry process). In the conventional accelerated corrosion tests (SST, JASO M609-91), specimens are sprayed with a 5 mass% NaCl solution, but in contrast, in the ACTE, salt deposition is performed by spraying or soaking the specimen with artificial seawater, considering the effect of airborne sea salt in the actual environment. The amount of deposited sea salt is set within a wide range, supposing corrosion environments ranging from coastal



amounts by obtaining dependency data for the effect of the chloride amount on the corrosion resistance of Zn-coated steel sheets. In this case, the corrosion resistance at low chloride amounts can be obtained from the relationship between the chloride amount and corrosion resistance by extrapolation based on the results of an evaluation at high chloride amounts. It is also possible to design the optimum corrosion resistance of materials corresponding to the use environment by investigating the dependency of the corrosion resistance of Zn-coated steel sheets on the Zn coating weight, paint film thickness, and similar factors.

3.2 Reproducibility of Actual Environments Using New ACTE Test Method

In order to verify the appropriateness of the evaluation results obtained with the ACTE test method, the reproducibility of actual environments was investigated by comparing the corrosion behavior in the ACTE and atmospheric exposure tests in Okinawa Pref.

As test specimens, painted steel sheets and chemical conversion coated steel sheets were used. Chromate-type pre-coated steel sheets (PCM: pre-coat metal), with hot-dip galvanized steel sheets (GI; coating weight: 30–90 $g \cdot m^{-2}$) and a cold rolled steel sheet (CRS) as the

the new ACTE test method and the exposure test in Okinawa Pref. for edge creep from the cut edges of painted steel sheets. Here, the saltwater concentration used in the ACTE is the concentration of artificial seawater during immersion in saltwater. Both the ACTE and the exposure test in Okinawa Pref. confirmed that edge creep shows a tendency to decrease as the Zn-coating weight of the substrate steel sheet increases. In the exposure test in Okinawa Pref., edge creep was larger with sheltered exposure, in which the amount of deposited sea salt was relatively heavy, in comparison with open exposure. In the ACTE, edge creep tended to increase with the saltwater concentration, and as a tendency, this agreed with the behavior in the exposure test in Okinawa Pref. On the other hand, with the SST and JASO test, a reversal in the corrosion resistance rankings of the test materials was observed, demonstrating that these tests have low correlations with the exposure test in Okinawa Pref.

The corrosion area ratios of the various types of chemical conversion coated steel sheets, including chromate-free steel sheets, were compared in an exposure test in Okinawa Pref. (sheltered, 1 year) and various other types of corrosion tests. As a result, it was found that the ACTE showed a good correlation with the exposure test in Okinawa Pref., independent of the type of chemical conversion coating, but with both the SST and the JASO test, the corrosion resistance ranking did not agree with that in the exposure test in Okinawa[25].

These results confirmed that the new ACTE test method has a high correlation with actual environments from the perspectives of corrosion morphology, amount of corrosion, corrosion resistance ranking, and effect of chloride amount. On the other hand, since an early date, it has been pointed out that the results of evaluations by the SST show a low correlation with actual environments[15–18], and this research also found a low correlation with actual environments from the viewpoints of corrosion morphology and corrosion resistance ranking. The present research also confirmed that the results of evaluations by the JASO test, which is a type of CCT, have a low correlation with actual environments. In other words, particularly in evaluations of materials with a short actual record of use, such as chromate-free steel sheets, these results suggest that evaluation by the SST or JASO test may result in not selecting a material which possesses adequate corrosion resistance for its intended use environment due to under-evaluation of it corrosion resistance, or conversely, selecting a material which fails to display corrosion resistance in the actual environment. In the former case, the maker may select an uneconomical over-spec material, and in the latter, the product may fail due to corrosion before reaching its assumed design life. In contrast, application of the new ACTE method enables an accurate evaluation of chromate-free steel sheets based on the actual environment.

3.3 Examples of Evaluation of Corrosion Resistance of Chromate-free Steel Sheets by New ACTE Test Method

Figure 7[24] shows the results of a comparison of the new ACTE test method and the conventional SST

used in electrical appliances, including chromate-free steel sheets.

(2) The conventional accelerated corrosion test methods (SST, JASO M 609-91) had a low correlation with corrosion in actual environments from the perspectives of the corrosion morphologies and corrosion resistance rankings of materials. Therefore, there is a danger that evaluations of chromate-free steel sheets by these methods may result in corrosion resistance evaluations which do not reflect the actual environment.

(3) With the new ACTE test method, it is possible to estimate the corrosion resistance life of materials in a wide range of use environments by obtaining dependency data for main corrosion factors (such as the amount of deposited sea salt, etc.) by varying the test conditions. It is also possible to design the optimum rust-prevention specifications of materials corresponding to the use environment of specific products.

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