10633 Session 2022
B2
PS2 Latest Techniques in Asset Management,
Capacity Enhancement, Refurbishment

Rationalization of maintenance methods for hot-dip galvanizing transmission tower

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SUMMARY

Steel structures such as transmission towers, bridges, plants, etc. exposed in various atmospheric environments are corroded by high humid weathers and depositions such as sea salt, corrosive gas, dust, etc. Therefore, hot-dip galvanizing and/or paint system are applied for these structures to prevent corrosion. Recently, hot-dip zinc-aluminum alloy galvanizing becomes popular as high corrosion resistance surface treatment. The range and quantity of depositions and time of wetness are the most important factors on atmospheric corrosion and under-film corrosion. However, it is still difficult to evaluate paint life accurately because under-film corrosion evaluation technique and appropriate accelerated degradation test method have not been established.
Therefore, our company has developed the life evaluation methods for corrosion of hot-dip galvanizing and other metals and paint degradation caused by under-film corrosion and the corrosion rate map and deposition concentration maps and time of wetness maps in Japan. These environmental maps have been very helpful for the application of corrosion control and protection methods and the decision of appropriate maintenance interval against corrosion.
In this paper, life evaluation and lifecycle cost assessment of hot-dip galvanizing, hot-dip zinc-aluminum alloy galvanizing, and paint system were conducted. The combined cycle accelerated corrosion tests according to ISO 16539 [1] indicated that the corrosion resistances of two types of hot-dip zinc-aluminum alloy galvanizing with and without magnesium were approximately 1,4 to 7,0 higher than that of hot-dip galvanizing and these amplifications depended on the environments. The UV irradiation accelerated degradation tests indicated that the lives of 3 paint systems having two-layer coating with a fluorocarbon polymer-based paint for the top coating and an epoxy-based paint for the under coating were more than 40 years.

KEYWORDS

Transmission – Tower, Maintenance, Corrosion, Deposition, Sea – Salt, Paint, Galvanizing

1. INTRODUCTION

Hot-dip galvanizing is used as a general corrosion prevention measure for transmission towers throughout Japan. These transmission towers are installed in various environments including coastal and rural areas and the thickness of hot-dip galvanizing layer is decreased by corrosion. Numerous transmission towers constructed from the mid-1950s to the early 1970s as the period of high economic growth have gotten close to the time of first painting before the loss of hot-dip galvanizing layer [2]. In 2020s, the proportion of the transmission towers in Japan exceeding 50 years in age is forecasted to be up to about 50 %. Thus, our company has applied various maintenance methods focusing on measures for metal corrosion and organic material degradation of transmission towers and other electric power equipment [3 – 5].

When the corrosion of carbon steel structure gets started after the loss of hot-dip galvanizing, the labor, time, and cost of the surface treatment such as descaling and cleaning are considerably required because the corrosion rate of carbon steel is about twenty times higher than that of hot-dip galvanizing and the amount of corrosion product of carbon steel is much higher than that of hot-dip galvanizing. And more, the labor, time, and cost of the regular corrosion inspection of each tower are too much. Therefore, it is very important to know the appropriate time for the first painting and maintenance planning. When we find the corrosion rate and remaining life of each transmission steel tower in various environments, we can adopt quick and low-cost maintenance planning method and we can reduce inspection time or extend inspection interval. Corrosion rate map and other environmental risk maps will deliver the advanced maintenance method.

In this study, life evaluation and lifecycle cost assessment of hot-dip galvanizing, hot-dip zinc-aluminum alloy galvanizing, and paint system on transmission towers were conducted with the combined cycle accelerated corrosion tests according to ISO 16539 [1] and the UV irradiation accelerated degradation tests.

Corrosion rate maps in Japan have been made by the multiple regression analysis of correlations between the corrosion rates of 150 transmission towers measured by atmospheric corrosion monitor (ACM) sensors [6, 7] and the 108 meteorological and topographical factors [8]. The corrosion rate data found by the maps are already applied on the maintenance for over 44000 transmission towers in our service area of Japan. This corrosion rate map can deliver the life and lifecycle cost of each transmission towers having different corrosion rate corresponding to the corrosive environments [9 – 11].

2. MAINTENANCE METHODS FOR HOT-DIP GALVANIZING TRANSMISSION TOWERS

We have evaluated the corrosion environment at more than 150 locations using ACM sensors capable of expecting the corrosion rate (see Figure 1) [4, 5, 9 – 11]. This extensive corrosion rate data is analyzed by statistical method to develop a map of the corrosion rate of the hot-dip galvanizing for use in transmission tower maintenance (see Figure 2). Corrosion rate maps of carbon steel and zinc in large areas of more than 200 km diameter which contained several prefectures were developed in 2006. Corrosion rates at points not being monitored were expected by multiple regression analysis, where objective variable is 38 corrosion rate data and explanatory variables are topographical factors and environmental factors such as data from meteorological office in Japan [8]. By comparison between estimated corrosion rate data delivered by the maps and galvanized layer thickness data of real transmission towers measured by maintenance engineers to reduce errors and enhance their utilities. The corrosion rate maps in whole Japan were developed with 150 corrosion rate data measured by ACM sensors in 2010 and enhance their utilities [4, 5, 9 – 11].

The corrosion rate map predicts the remaining thickness of the hot-dip galvanizing on transmission towers in various environments. The time when the thickness of hot-dip galvanizing is depleted to 30 to 15 μm due to corrosion is the appropriate and cost-effective timing for the first painting of transmission tower because the life of organic coating on the hot-dip galvanizing remaining surface will become longer than that on the carbon steel surface after the loss of the hot-dip galvanizing. The remaining hot-dip galvanizing has still a function of sacrificial protection of steel structure. On the other hand, it is quite tough surface treatment for corroded carbon steel to eliminate the steel corrosion product perfectly and the remaining steel corrosion product accelerates the corrosion reaction of steel structure because of its own oxidation and reduction reactions of Fe^{2+} and Fe^{3+}. The transmission towers can be maintained by the paint system with corrosion-proof organic coatings such as two-layer coating system with a fluorocarbon polymer-based paint for the top coating and an epoxy-based paint for the under coating. The lifecycle cost utilizing the assessment of the corrosion resistance of hot-dip zinc-aluminum alloy galvanizing and the assessment of the remaining life of the standard organic coating was calculated, and the maintenance methods for hot-dip galvanizing transmission towers were rationalized for each environment.

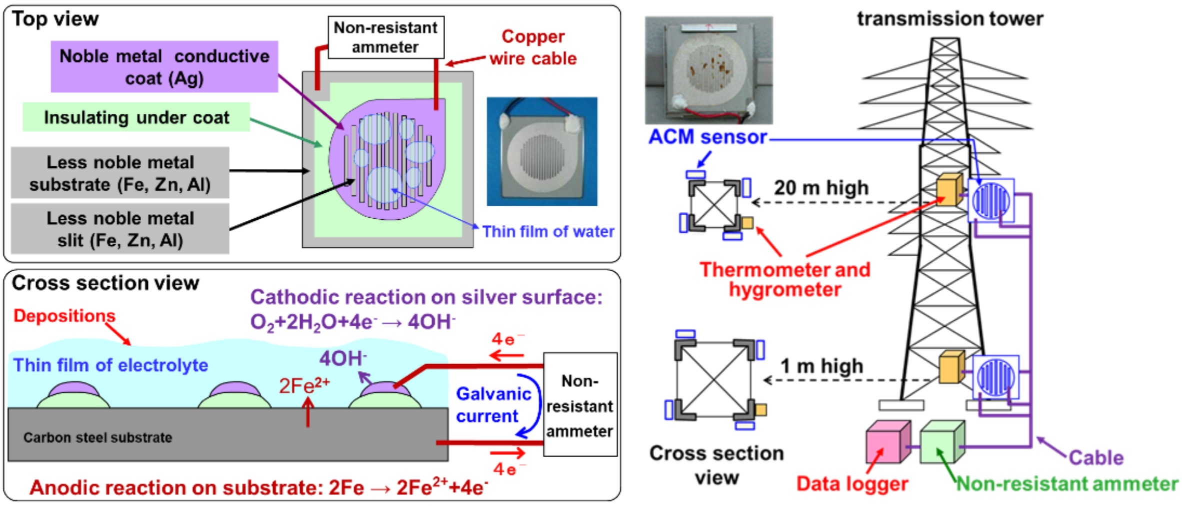

Figure 1. Schematic diagrams of ACM sensor and corrosion monitoring system on transmission tower

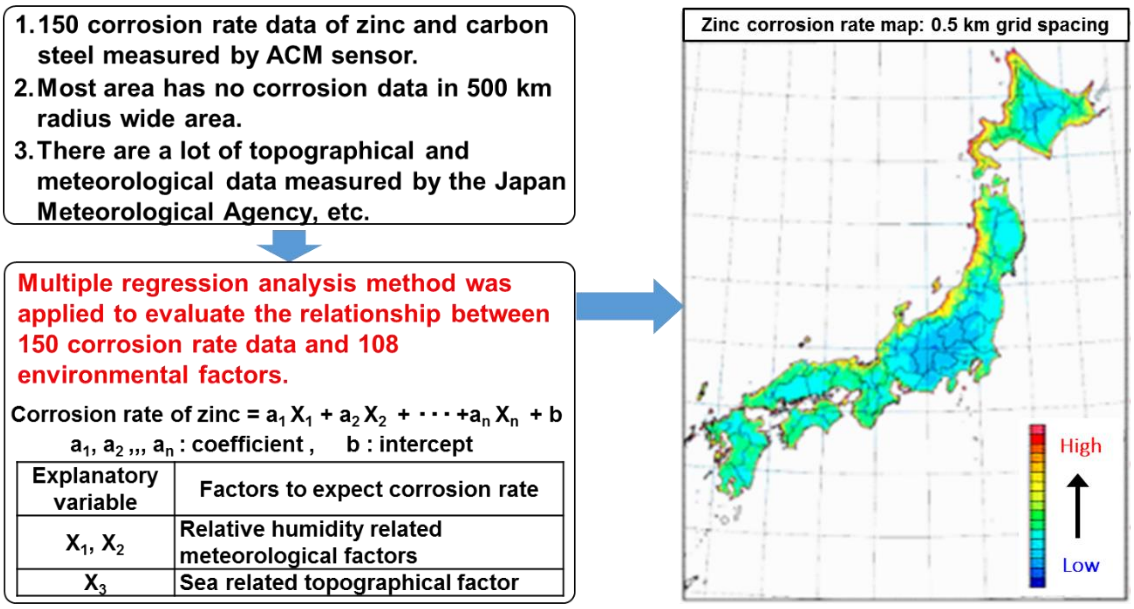

Figure 2. Corrosion rate map of hot-dip galvanizing

3. CORROSION RESISTANCE OF HOT-DIP GALVANIZING AND HOT-DIP ZINC-ALUMINUM ALLOY GALVANIZING

There are cases that the corrosion rate of the hot-dip galvanizing of transmission towers in coastal areas are much faster than those in rural areas. Some transmission towers under these severer corrosive environments have lost the hot-dip galvanizing and gotten steel corrosion, resulting the miss of optimum time for applying the corrosion-proof organic coating. For severer corrosive environments, we add the specification of a hot-dip zinc-aluminum alloy galvanizing transmission towers. This hot-dip zinc-aluminum alloy galvanizing has about twice or thrice higher corrosion resistance than the hot-dip galvanizing. Two different types of hot-dip zinc-aluminum alloy galvanizing with and without magnesium (94% Zn, 5% Al, 1% Mg, and 93% Zn, 7% Al) have been adopted (see Figure 3). Corrosion resistances of two types of hot-dip zinc-aluminum alloy galvanizing were evaluated by the combined cycle accelerated corrosion test conforming with ISO 16539 [1], which is considered to be the closest to realistic corrosion in the environment (see Figure 4). Exposure corrosion tests also conducted at various locations in Japan. The corrosion weight loss of two types of hot-dip zinc-aluminum alloy galvanizing after 12 cycles of ISO 16539 combined cycle accelerated corrosion test [1] provide approximately 1,4 to 1,7 times lower than that of hot-dip galvanizing when the amounts of deposited artificial sea water on them is 10^{-3} g.m^{-2} as the simulation of mild corrosive environment. On the other hand, the corrosion weight losses of two types of hot-dip zinc-aluminum alloy galvanizing provides approximately 2,3 to 7,0 times lower than those of hot-dip galvanizing when the amounts of deposited artificial sea water are 10^{-2} to 10 g.m^{-2} as the simulation of severe corrosive environment (see Table I and Figure 5). The amount of deposited artificial sea water equals the amount of NaCl assumed that the total chloride ion Cl^- in the artificial sea water is combined with sodium ion Na^+. In this experiment, the weight loss measurement might have large error because of uniform chemical descaling. The experiment will be done again to get more precise weight loss data in the near future.

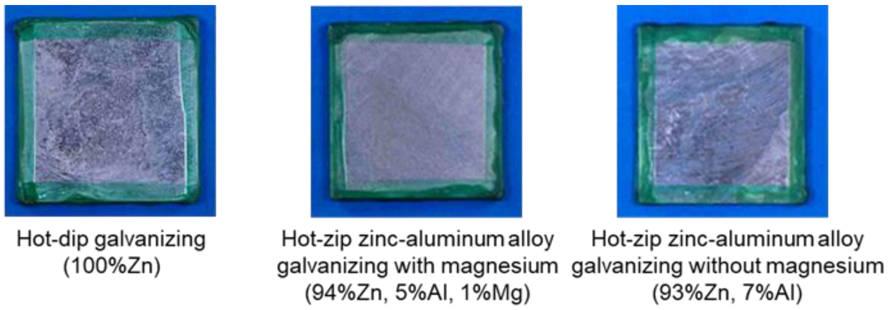

Figure 3. Specimens of hot-dip galvanizing and hot-dip zinc-aluminum alloy galvanizing with and without magnesium for combined cycle accelerated corrosion test

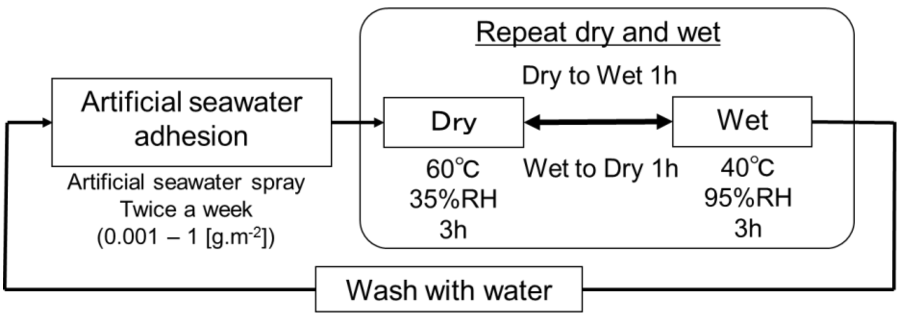

Figure 4. Combined cycle accelerated corrosion test condition according to ISO 16539 [1]

Table I. Corrosion weight loss of hot-dip galvanizing and hot-dip zinc-aluminum alloy galvanizing

Amounts of deposited artificial sea water on the test specimen for ISO 16539 combined cycle accelerated corrosion test* [g.m^{-2}]	Corrosion weight loss of the test specimen after 12 cycles of ISO 16539 combined cycle accelerated corrosion test		
	Hot-dip galvanizing (100%Zn) [g.m^{-2}]	Hot-dip zinc-aluminum alloy galvanizing with magnesium (94%Zn, 5%Al, 1%Mg) [g.m^{-2}]	Hot-dip zinc-aluminum alloy galvanizing without magnesium (93%Zn, 7%Al) [g.m^{-2}]
10^{-3}	5	3	3
10^{-2}	9	4	2
10^{-1}	28	5	6
1	146	21	31
10	314	83	105

*: Amount of deposited artificial sea water equals the amount of NaCl assumed that the total chloride ion Cl^- in the artificial sea water is combined with sodium ion Na^+.

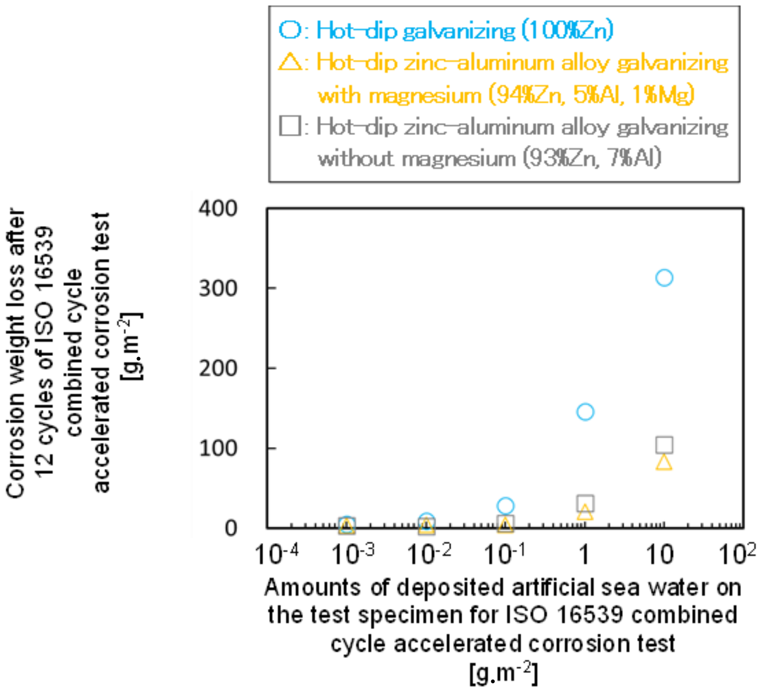

Figure 5. Assessment of corrosion weight loss of hot-dip galvanizing and hot-dip zinc-aluminum alloy galvanizing after 12 cycles of ISO 16539 combined cycle accelerated corrosion test

4. LIFE ASSESSMENT OF ORGANIC COATING FOR TRANSMISSION TOWERS

We used a wide variety of paints for corrosion-proof in the past, including epoxy-based and polyurethane-based paints, but in the mid-90's the company unified on a two-layer paint system with a fluorocarbon polymer-based paint for the top coating and an epoxy-based paint for the prime coating (hereinafter "the standard coating"). More than 20 years have passed since the standard coating was introduced. However, it is necessary to assess the life of the paint systems based on the depletion or erosion rate of the top coating as well as the under-film corrosion rate, and long-term exposure test used to be required for the reproducibility [12, 13]. It is very tough work to choose an appropriate accelerated degradation test method and a degradation evaluation method of paint system because there is a lot of accelerated degradation test methods and a lot of degradation evaluation methods and there is almost no threshold to determine the precise life of paint system. Moreover, accelerated degradation tests are used to take much time to get comparably precise life of paint system. There is a lot of life evaluation data of paint system caused by depletion or erosion. There is quite a few life evaluation data of paint system caused by under-film corrosion, even though the paint system life and repaint timing are determined by under-film corrosion [14, 15]. The long-term under-film corrosion resistance performance and appropriate repaint timing of the standard coating had still not been identified, or in other words the paint system life was not expected precisely.

In this study, some paint system degradation diagnosis techniques are applied for real transmission tower paint system. We have recommended to paint transmission towers with the condition that the hot-dip galvanizing still remains on the surface. However, in order to assess the paint system life conservatively in a short period of time, the base material for the painted test pieces made of steel plates without hot-dip galvanizing were used to make blister and swelling quickly caused by larger volumetric expansion of corrosion product. The test pieces were painted with the standard coating. An UV irradiation accelerated degradation test was performed in metal halide weather meter [16] (see Figure 6). The light source of the ultraviolet region of the metal halide weather meter is 20 times more intense than solar rays in normal outdoor environments in Japan [8].

The paint system test pieces have been irradiated for 1300 hours to 6500 hours corresponds to 10 years to 50 years in normal outdoor environments in Japan (see Figure 7), to compare the paint system lives between the standard coating. Two same types of paint system, Paints A and B, which contain the same base polymer and component and made by different manufacturers and one type of coating that was used in the past (Paint C). These 3 corrosion-proof paint systems have two-layer coating with a fluorocarbon polymer-based paint for the top coating and an epoxy-based paint for the under coating.

Blisters of 3 paint systems caused by under-film corrosion were not observed up to the accelerated test period equivalent to 40 years of UV irradiation. Under-film corrosion of 3 paint systems occurred after the accelerated test period equivalent to 50 years of UV irradiation. Consequently, the lives of 3 paint systems were estimated to be 40 to 50 years (see Figure 8). The blister diameter of Paint C was much larger than that of Paint A and Paint B. Therefore, it was expected that the life of Paint C was comparably shorter than that of Paint A and Paint B. The under-film corrosion in the blister will be observed to evaluate precise life of paint systems in the near future.

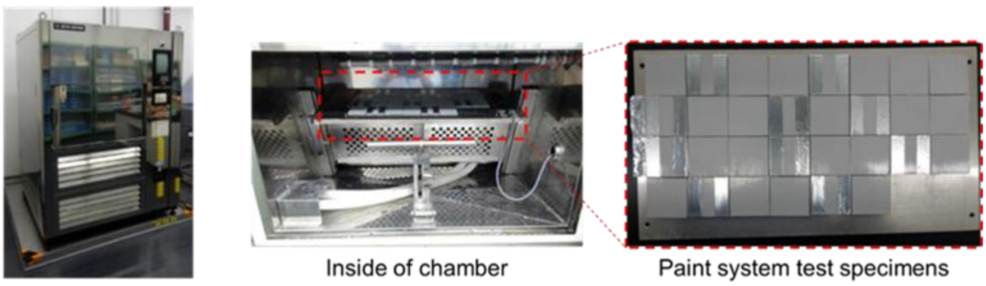

Figure 6. Metal halide weather meter type UV irradiation accelerated degradation test equipment and test specimens

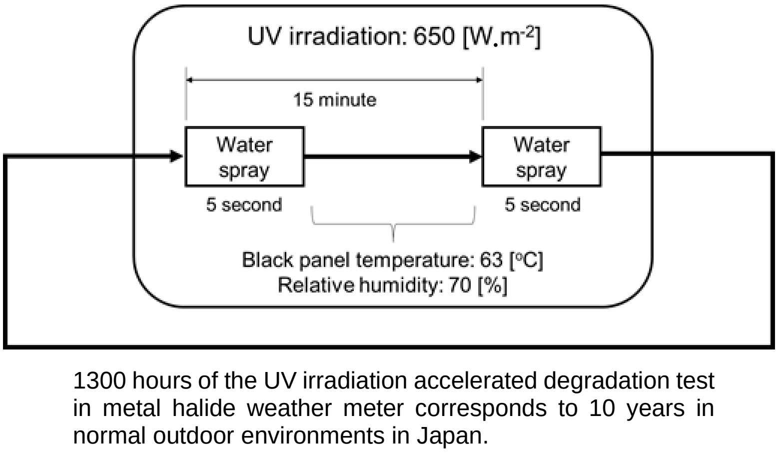

Figure 7. UV irradiation accelerated degradation test condition

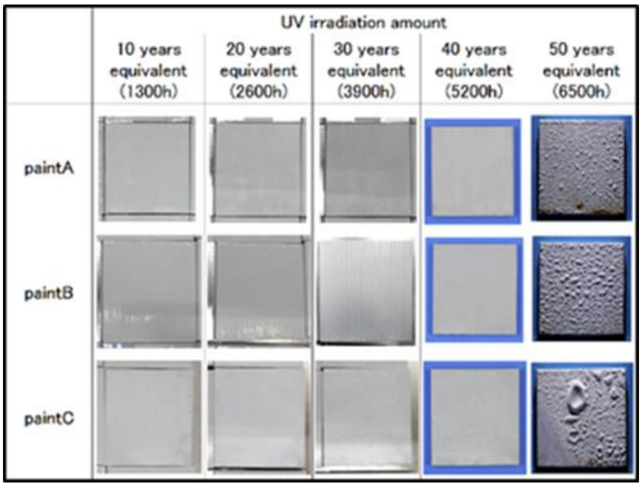

Figure 8. Surface observation result after UV irradiation accelerated degradation tests

5. LIFECYCLE COSTS COMPARISON OF TRANSMISSION TOWERS

From the results of the combined cycle tests conforming with ISO 16539 [1], it was assessed that corrosion resistant hot-dip zinc-aluminum alloy galvanizing with the deposited sea salt was approximately 2,3 to 7,0 times higher than zinc galvanizing. Furthermore, metal weather testing after the accelerated test period equivalent to 50 years of UV irradiation showed that the expected life of the standard coating was approximately 40 years.

Based on these results, lifecycle costs were compared using a 275 kV transmission tower of which the weight was 49 ton as a model. In a rural area corresponding to the mild corrosive environment which had 10^{-3} $g.m^{-2}$ of sea salt adhesion and 1,0 $\mu m.year^{-1}$ of annual zinc corrosion rate, the lifecycle cost of the painting repeated with appropriate timing on the hot-dip galvanizing transmission towers was significantly lower than the others (see Figure 9). The initial cost of transmission tower with hot-dip galvanizing was subtracted to deliver the cost differences. The initial costs of hot-dip zinc-aluminum alloy galvanizing with magnesium (94%Zn, 5%Al, 1%Mg), hot-dip zinc-aluminum alloy galvanizing without magnesium (93%Zn, 7%Al), and hot-dip galvanizing (100%Zn) and factory painting also decrease the initial cost of transmission tower with hot-dip galvanizing in Figure 9.

On the other hand, in a coastal area corresponding to the severe corrosive environment which had 10^{-1} $g.m^{-2}$ of sea salt adhesion and 4,5 $\mu m.year^{-1}$ of annual zinc corrosion rate, the lifecycle cost of the painting repeated with appropriate timing on the hot-dip zinc-aluminum alloy galvanizing with magnesium (94% Zn, 5% Al, 1% Mg) transmission towers was significantly lower than the others (see Figure 10). The initial cost of transmission tower with hot-dip galvanizing was subtracted to deliver the

cost differences. The initial costs of transmission towers with each galvanizing and factory painting decrease the initial cost of transmission tower with hot-dip galvanizing as same as Figure 9.
It is revealed that the lifecycle cost of transmission towers strongly depends on the corrosivity of environments. A good corrosion control will extend the life of galvanizing and paint system and reduce the lifecycle cost of transmission towers.

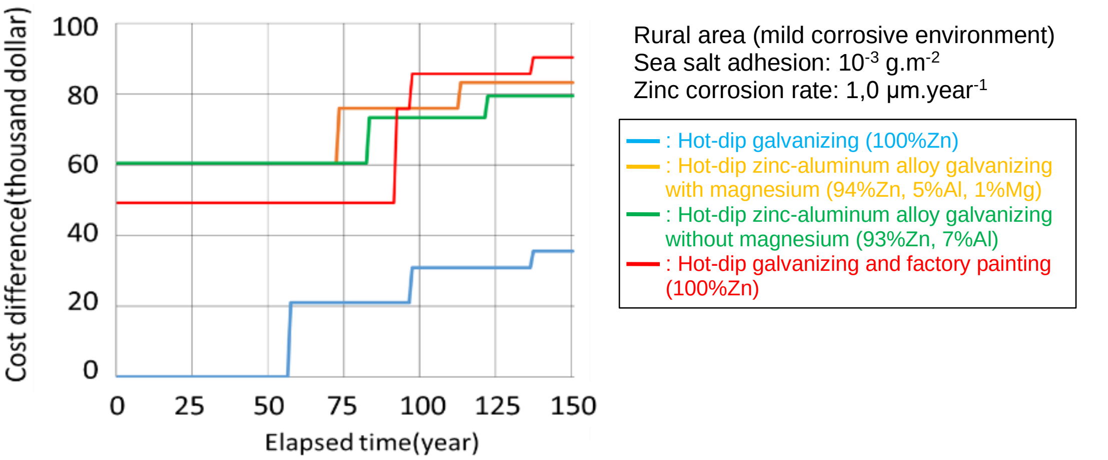

Figure 9. Lifecycle cost differences comparison of transmission towers with different type of galvanizing and factory painting in rural area (The initial cost of transmission tower with hot-dip galvanizing was subtracted to deliver the cost differences.)

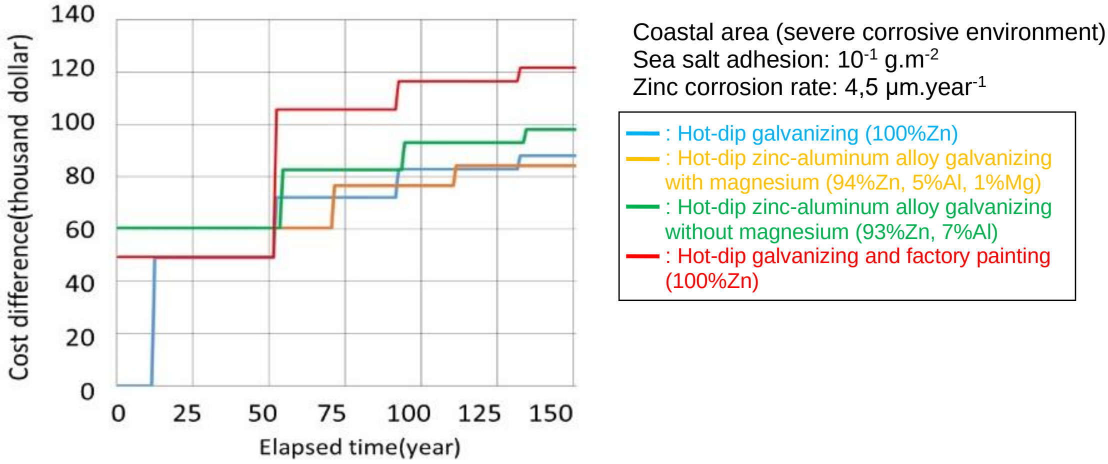

Figure 10. Lifecycle cost differences comparison of transmission towers with different type of galvanizing and factory painting in coastal area (The initial cost of transmission tower with hot-dip galvanizing was subtracted to deliver the cost differences.)

6. CONCLUSION

a) In order to evaluate specification, maintenance methods focusing on measures for metal corrosion and organic material degradation of transmission towers made of carbon steel with hot-dip galvanizing and/or paint system, we reported the corrosion rate, degradation rates, and lifecycle cost assessment in various environment.
b) The corrosive environment was evaluated with ACM sensors and corrosion rate maps were developed from numerous corrosion related data and statistical method.
c) 12 cycles of ISO 16539 combined cycle accelerated corrosion tests provide that the corrosion resistances of two types of hot-dip zinc-aluminum alloy galvanizing with and without magnesium were slightly higher than that of hot-dip galvanizing in mild corrosive environment which had 10^{-3}

g.m^{-2} of sea salt adhesion and were several times higher in severe corrosive environment which had 10^{-2} to 10 g.m^{-2} of sea salt adhesion.

d) UV irradiation accelerated degradation tests with the metal weather test chamber provide that the lives of 3 paint systems having two-layer coating with a fluorocarbon polymer-based paint for the top coating and an epoxy-based paint for the under coating were estimated to be 40 to 50 years.

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