Relation between corrosion level and composition of accumulating salt on the weathering steel bridges

M. Takebe¹, M. Ohya¹, S. Ajiki², T. Furukawa³, Y. Matsuzaki⁴ and T. Aso⁵

1. Matsue National College of Technology, Matsue, Japan
2. Izucon Co. Ltd., Nagoya University, Izumo, Japan
3. Furukawa consultant, Izumo, Japan
4. WESCO Inc., Matsue, Japan
5. Department of Civil and Environmental Engineering, Faculty of Engineering, Yamaguchi University, Ube, Japan

Abstract: To discuss the relation of accumulating salt and corrosion state on weathering steel bridges, we investigated chemical state of salt and corrosion state on the bridges in southwestern Japan. Quantities of Na⁺ and Cl⁻ on girders are positively correlated with rust thickness and corrosion rank, indicating that the accumulating ions enhance the corrosion. Relative to web, lower flange is enriched in Na⁺ and Cl⁻, and shows worse corrosion feature. The enrichment of ions on lower flange probably results from migration of accumulating salt from web to lower flange due to rain and dew.

Keywords: weathering steel bridge, accumulating salt, corrosion level

1. INTRODUCTION

Due to additive of small amount of Cr and Cu, weathering steels is covered with protective rust during corrosion. As a result, weathering steels have high resistance of corrosion and can be used for constructions without anticorrosion coating. Hence, weathering steels can cut down cost for maintenance about anticorrosion coating. In order to reduce life cycle cost, weathering steels is widely used for infrastructures. Because the corrosion loss is related to deposition rate of air-born salt, Japanese Roads and Bridges Policy Manual [1] recommended that specification of weathering steel is determined on the basis of deposition rate of air-born salt. However, corrosion of steels is directly influenced not by air born salt but by accumulating salt. Hence, knowledge about composition and behavior accumulating salt on weathering steel is needed to precisely discuss corrosion environment for weathering steels in an area. In this study, we analyzed chemical composition of accumulating salt and corrosion level on weathering steel bridges in Shimane, southwestern Japan, and discuss the influence of accumulating salt on the corrosion of weathering steel bridges.

Westerly wind plays an important role for supplying air-born salt form sea in Japan. Because Shimane is close to Japan Sea, which is located in west of Japan, air-born salt from sea is abundantly supplied and corrosion of weathering steel bridges is enhanced in Shimane [1]. In addition, there are many weathering steel bridges with several to a few tenth years old in Shimane. Therefore, Shimane is a suitable place to examine the applicability of weathering steel bridges under the condition that the air-born salt is abundantly supplied.

2. ANALYZED BRIDGES and METHOD

Fig. 1 shows the localities of analyzed bridges and analyzed site on the bridges. Accumulating salt on a bridge is sampled by wiping with gauzes. The sampled salt was dissolved in pure-water, and the quantities of ions in the water are analyzed by ion-exchange chromatography.

The rust state at the examined sites of bridges was ranked by visual inspection and thickness of rust, following the method of [2, 3, 4]. The rust thickness was measured by electro-magnetic coating thickness meters.

3. RESULTS

3.1. General property of chemical composition of accumulating salt

Fig. 2 shows stiff diagrams [5] of composition of accumulating salt on girders and seawater [6]. Accumulating salts on examined bridges are composed mainly of Na⁺, Ca²⁺, Cl⁻ and SO₄²⁻. In many case, Na⁺ and Cl⁻ are dominant. Na⁺ and Cl⁻ show positively correlated, and correlation value (R) is beyond 0.9 (Fig. 3a). In all analyzed bridge, outer surface of the outer girder shows extremely low quantities of accumulating ions relative to the other analyzed sites. On the other hand, upper surface of lower flange generally shows high quantities of accumulating ions. The lower flange is generally enriched in Na⁺ and Cl⁻. Chemical composition of accumulating salt shows some variation related to the locality of bridges.

3.2. Variation of chemical composition of accumulating salt

3.2.1. Bridge A, C, D and E (bridges around plane and lakes)

Accumulating salt on bridges are commonly rich in Na⁺ and Cl⁻, except for inside-ward surface of web in Bridge A, E and D, which show higher quantities of Ca²⁺ and SO₄²⁻ than those of Na⁺ and Cl⁻. Among these
bridges, quantities of Ca\(^{2+}\) and SO\(_4^{2-}\) show distinctly positive correlation (Fig. 3b). The slope of the correlation line is similar to that of CaSO\(_4\).

3.2.3. Bridge B, F and G (mountain area)

Inside-ward surface of web and upper surface of lower flange are rich in Na\(^+\) and SO\(_4^{2-}\). Accumulating salt on lower flange consists of Ca\(^{2+}\) and Cl\(^-\) in addition to Na\(^+\) and SO\(_4^{2-}\). Quantity of Na\(^+\) is positively correlated with the quantities of Cl\(^-\) + SO\(_4^{2-}\) (Fig. 3c). The slope of the correlation line is close to 1, in terms of equivalent unit.

3.2.4. Bridge H, I, J and K (areas along to shore line)

Na\(^+\) and Cl\(^-\) are dominant on girder of Bridge H, I and J. The quantities of Na\(^+\) and Cl\(^-\) on Bridge H and I, which are close to shoreline, are up to several 100 to several 1000 mg/m\(^2\). Chemical compositions of accumulating salt on these bridges are similar to that of seawater. Bridge K is extremely enriched in Ca\(^{2+}\) and SO\(_4^{2-}\). The girders of Bridge K are covered by the yellowish-white powder of gypsum.

3.3. Rust inspection

Corrosion rank (1, 2, 3, 4, 5, A, B) is the proxy indicating corrosion state. Low values of the rank indicate worse corrosion state. Rank-1 correspond to the feature that bumpy rusts larger than 25 mm or seat-like detachment of rust are found. Additional anti-corrosion maintenances are necessary in the case of Rank-1. Rank-2 is previous stage of Rank-1, and intensified inspection is needed in the case. Corrosion rank is also related to the thickness of rust.

In Bridge A, B, C, D, E, and J, rust with thickness beyond 500 \(\mu\)m is only found on lower flange. Other site of these bridges is classed as Rank-3, 4, 5, A or B. Lower flange of Bridges A, D and E is classed as Rank-5. In Bridge H and I, there are many sites in which thickness of rust generally ranges 500 to 1000 \(\mu\)m. Corrosion on girders of these bridges has entirely progressed. Except for outside surface of web, corrosion state on these bridges are classed as Rank-2.
4. DISCUSSION

The correlation between Na\(^+\) and Cl\(^-\) suggests that these ions are derived from the same origin. Because bridges close to shoreline have high quantities of these ions and show chemical composition similar to seawater, Na\(^+\) and Cl\(^-\) are considered to originate mainly from seawater.

Accumulating salt on bridges located at less than 2 km from shoreline are extremely enriched in Na\(^+\) and Cl\(^-\) relative to other ions. These ions may accumulate mainly as NaCl. On bridges far from shoreline, quantities of Ca\(^{2+}\) and SO\(_4^{2-}\) are comparable to those of Na\(^+\) and Cl\(^-\). The ratios of Ca\(^{2+}\)/Cl\(^-\) and SO\(_4^{2-}\)/Cl\(^-\) are higher than those of seawater, suggesting that Ca\(^{2+}\) and SO\(_4^{2-}\) originate not only from seawater. The distinctive correlation of quantities of Ca\(^{2+}\) and SO\(_4^{2-}\) on Bridge A, C, D and E suggests that Ca\(^{2+}\) and SO\(_4^{2-}\) are accumulating as CaSO\(_4\) on these bridges. While, the distinctive correlation between quantities of Na\(^+\) and Cl\(^-\)/SO\(_4^{2-}\) on Bridge B, F and G suggests that there is NaSO\(_4\), as well as NaCl, on these bridges. In summary, bridges close to shoreline are extremely enriched in Na\(^+\) and Cl\(^-\), while quantities of CaSO\(_4\) and NaSO\(_4\) relative to NaCl is increased in accumulating salt on bridges that are far from shoreline. The SO\(_4^{2-}\) is potentially originated from seawater, acid rain, chemical fertilizers agrochemicals, concrete, asphalt, dimethyl sulfate yield by marine plankton, and so on. However, there is still no conclusive evidences for the origin of the SO\(_4^{2-}\) on bridges. Hence, further studies are needed to identify the origin of SO\(_4^{2-}\).

Quantities of Na\(^+\) and Cl\(^-\) accumulating on girders are positively correlated with thickness of rust and rank of corrosion (Fig. 4), indicating that accumulating Na\(^+\) or Cl\(^-\) enhance the corrosion. Girders with higher quantities of Na\(^+\) and Cl\(^-\) than 200 mg/m\(^2\) often show worse rank of corrosion state.

Outer surface of web always shows low quantities of accumulating ions and the corrosion do not have progressed so much, although the outer surface of web is probably a site in which air bone salt is abundantly supplied. The low quantities are probably caused by that the outer surface is easily washed by rain. Compared with the inside-ward surface of web, surface of the lower flange is enriched in Na\(^+\) and Cl\(^-\), and shows worse corrosion rank. While rain is not supplied to the inside-ward surface of web, dew potentially forms on the surface. In fact, flow traces of dew are generally found on the inside-ward surface of web. Hence, salt accumulating on web is considered to migrate to lower flange due to flow of dew. As a result, lower flange is probably enriched in salt and corrosion of lower flange has progressed.

4. SUMMARY

In this study, composition of accumulating salt and corrosion rank on weathering steel bridges in Shimane southwestern Japan are examined. As a result, following summary is obtained.

1. Bridges close to shoreline are extremely enriched in Na\(^+\) and Cl\(^-\), while quantities of CaSO\(_4\) and NaSO\(_4\) relative to NaCl is increased in accumulating salt on bridges that are far from shoreline.

2. Quantities of Na\(^+\) and Cl\(^-\) accumulating on girders are positively correlated with thickness of rust and rank of corrosion, indicating that accumulating Na\(^+\) and Cl\(^-\) enhance corrosion of weathering steels.

3. Lower flange is generally enriched in salt and shows worse corrosion state, compared with web. These differences probably result from migration of salt from web to lower flange by rain and dew.
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