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3%-Ni Weathering Steel Plate for Uncoated Bridges at High Airborne Salt Environment

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Abstract

3%-Ni weathering steel for uncoated bridges in high air-born salt environments was developed. The ion exchanging functions of the rust layer formed on the 3%Ni-weathering steel play an essential role on giving its high weathering performance. For more successful applications of the new weathering steel for uncoated brides, it is recommended to make use of estimation methods of long-term penetration which give consideration to main environmental factors such as time of wetness, air-born salt deposition rate, mean-temperature etc.

1. Introduction

As social infrastructure has been accumulated and aged in Japan and the country's birth rate has declined leading to possible decrease in manpower for an extended period in the future, corrosion protection measures to realize long service life and reduction of maintenance costs are highly required in relation to new bridge constructions. Typically, the requirement is expressed in the concept of Minimum Maintenance Bridges proposed by the Ministry of Land, Infrastructure and Transport[1)]. Weathering steel, whereby maintenance costs for repainting work are reduced, is attracting attention as a promising material to realize both the long service life and the reduction of maintenance costs.

A weathering steel is a low alloy steel containing small amounts of corrosion resistant elements such as Cu, Cr and Ni. During its use without painting, compact and protective rust having good adhesion forms on steel surfaces, which suppresses further progress of corrosion to a sufficiently low level. The application of weathering steel to steel bridges began in the 1960s in Japan, and it was used for more than 3,000 bridges up to 1996. The ratio of its application to the whole steel weight of bridges has also increased year by year to exceed 14% at present[2)]. In coastal locations, however, the protective rust does not always form as designed owing mainly to airborne sea salt, resulting in lamellar exfoliation of rust layers. In view of the situation, unpainted use of the weathering steel for bridges is recommended, without requiring actual measurement of the airborne sea salt, only at locations where the deposition of airborne sea salt is 0.05 mdd (mg/100 cm^2/day) or less (see **Fig.1**[3)]).

However, many urban centers of Japan are located in coastal plains and consequently, many interurban roads run near the sea. Furthermore, because spiked tires have been banned, use of road deicing salt in winter has increased in cold districts. Because of these particular situations in Japan, development of a new weathering steel applicable to bridges in the districts where the deicing salt is used without painting, or a weathering steel excellent in salt corrosion resistance, has been eagerly awaited.

Nippon Steel Corporation set about developing new weathering steel excellent in salt corrosion resistance in the 1980s. Ever since then, the company has studied the design concept of protective rust having good salt corrosion resistance[4,5)]. It has also carried out de-

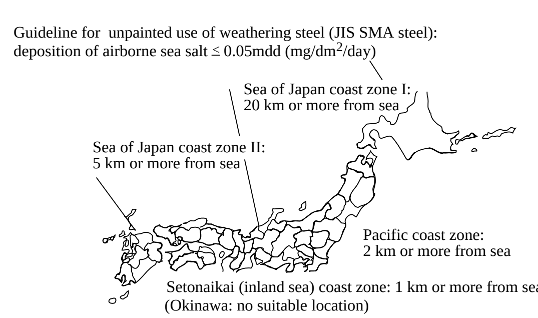

Fig. 1 Guideline for application of unpainted steel to bridges (conventional weathering steels)

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Table 1 Examples of actual chemical composition of 3%-Ni weathering steel

	C	Si	Mn	P	S	Cu	Ni	Cr	V	P_{cm}*
SMA400W-MOD	0.06	0.18	0.50	0.006	0.002	0.34	3.06	0.02	—	0.16
SMA490W-MOD	0.06	0.20	0.85	0.005	0.002	0.32	3.05	0.02	—	0.18
SMA470WQ-MOD	0.06	0.20	1.36	0.004	0.002	0.34	3.06	0.02	0.02	0.20
(Ref.) JIS G 3114	≤ 0.18	0.15/0.65	≤ 1.40	≤ 0.035	≤ 0.035	0.3/0.5	0.05/0.30	0.45/0.75	—	—

*P_{cm}=C+Si/30+Mn/20+Cu/20+Ni/60+Cr/20+Mo/15+V/15+5B

velopment/verification tests such as trial production of high-Ni steels for bridges, environmental exposure tests for more than 9 years and test applications to bridges in its own steelworks. As a result, after a series of quality verification tests, Nippon Steel launched in 1998 a plate product of weathering steel for bridges to the market, together with special welding material and high tension bolts for the product[6-14]. Its application to real bridges began with a Shinkansen (bullet train) viaduct over Hokuriku Expressway 600 m away from the Oyashirazu coast of the Sea of Japan (in the Sea of Japan zone I in Fig. 1)[15] and then steadily expanded to count an accumulated amount over 9,000 tons for more than 30 roadway and railway bridges/viaducts as of December 2001. This paper reports the design philosophy and corrosion protection mechanism of the developed 3%-Ni weathering steel having enhanced salt corrosion resistance.

2. Outline of 3%-Ni Weathering Steel

Table 1 shows some examples of the chemical composition of the developed 3%-Ni weathering steel. On the basis of 3% addition of Ni and no addition of Cr for realizing enhanced salt corrosion resistance, the contents of other elements are defined within the ranges specified in JIS G 3114 "Hot-rolled atmospheric corrosion resisting steels for welded structures" so as to meet the mechanical properties specified therein. Heavy plates (up to 100 mm in thickness) of the developed steel having tensile strengths of 400, 490 and 570 N/mm^2 are made available.

In addition, special welding material and high-tension bolts, necessary for building steel structures with the developed steel plates, containing 3% of Ni and no Cr, are also made available. They have been confirmed to have sufficient performance as bridge construction materials[16]. The welding material contains the same level of Ni as the 3%-Ni weathering steel to be welded and for the purpose of improving the solidification crack sensitivity of weld metal, the C content of the base metal is reduced to 0.06%[17].

3. Composition Design Philosophy of 3%-Ni Weathering Steel and Mechanism to Improve Salt Corrosion Resistance

3.1 Design guideline of rust

It has been made clear through examination of rust layers forming in environments of high airborne salt concentration that in the rust layers of conventional weathering steels, chloride ions (Cl^-) penetrate through an inner rust layer to the interface with steel substrate and condense there, and sodium ions (Na^+) exist from middle to outer rust layers, separate from the chloride ions (see **Fig. 2**). In the inner rust layer and the interface with steel substrate where the chloride ions are enriched, it is presumed that dissolution of steel substrate, namely its corrosion, is accelerated by a low pH value and high concentration of chloride ions owing to hydrolysis of dissolved Fe ions. The above phenomenon of the chloride ions enriched beneath the rust layers causing the advancement of corrosion is similar to that occurring in a pitting corrosion portion of stainless steel where chloride ions are enriched and the value of pH is lowered[18].

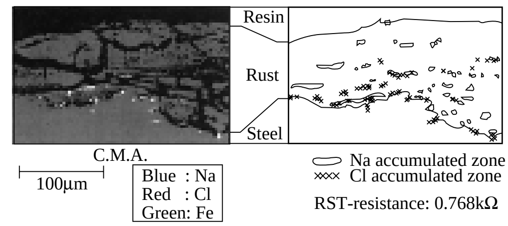


Fig. 2 Element distributions at cross section of rust on conventional weathering steel affected by airborne salt (EPMA analysis)

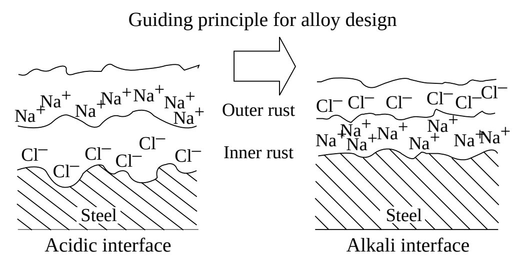


Fig. 3 Guiding philosophy for design of protective rust layers having enhanced salt corrosion resistance (alkalization of rust interface by control of ion exchanging function of rust layers)

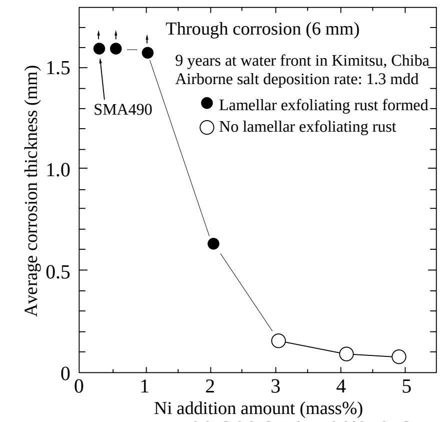
If steel's chemical composition is so designed that rust has such an ion exchanging function that chloride ions concentrate in the outer rust layer and sodium ions in the inner rust layer as shown in **Fig. 3**, the penetration of chloride ions to the interface with the steel substrate, their enrichment there and the lowering of the pH value will be inhibited and the dissolution of the steel substrate will be suppressed as a result. This is the basic philosophy in the composition design of the 3%-Ni weathering steel.

3.2 Verification of salt corrosion resistance through exposure test in coastal environment

The authors investigated the influence of Ni over the weathering properties in high-airborne sea salt environments through environmental exposure tests at several coastal locations. **Fig. 4** shows the relationship between the amount of Ni addition and the average thickness loss calculated from the corrosion weight loss after a 9-year exposure. Judging from the corrosion rate and occurrence or otherwise of lamellar exfoliating rust, Ni addition amount of 2% is insufficient and 3% of Ni addition is required for realizing good salt corrosion resistance. **Fig. 5** shows corrosion curves of a conventional weathering steel and the developed 3%-Ni weathering steel. It is clear from the figure that the rust layers formed on the 3%-Ni weathering steel have sufficiently good protecting function in a high airborne salt environment.

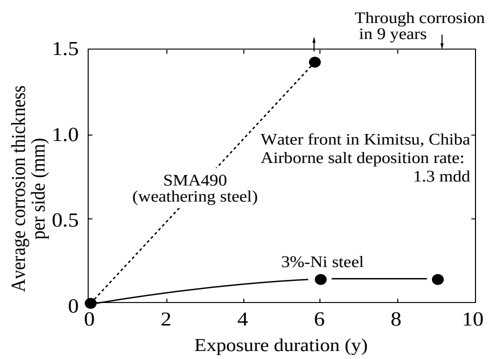
3.3 Characteristics of protective rust of 3%-Ni weathering steel

The protective rust of a conventional weathering steel[19] and that of the developed 3%-Ni weathering steel have the following common characteristics: (1) the rust can be divided into two layers; (2) a continuous layer appearing dark under a polarized microscope is formed as an inner layer; (3) the inner dark layer yields non-crystal-



Base composition: 0.05C-0.05Si-1.0Mn-0.008P-0.4Cu-xNi

Fig. 4 Influence of Ni addition amount over coastal weathering performance



Base composition: 0.05C-0.05Si-1.0Mn-0.008P-0.4Cu-3Ni

Fig. 5 Corrosion-time curve of 3%-Ni weathering steel

lized patterns either at an X-ray diffraction analysis or laser Raman spectroscopy; and (4) corrosion resistant elements (Cu, Cr and Ni in the former, and Cu and Ni in the latter) are enriched, some uniformly and the other(s) locally, in the inner dark layer.

Fig. 6 shows element distributions in the rust layers formed on the 3%-Ni weathering steel after a 9-year exposure at a coastal location. It is clear in the figure that the desired characteristic to keep chloride ions in the outer layer of the rust and have sodium ions concentrate in the inner layer, separate from the chloride ions, is realized, which means that the rust has the structure reflecting the design philosophy of the highly protective rust shown in Fig. 3. This ion exchanging function is presumed to be due to Ni and Cu distributed in the inner rust layer. It is considered that the inner rust layer and its interface with the steel substrate are in a high-alkali, thanks to the ion exchanging function, and low-Cl environment and corrosion resistant Ni and Cu form the compact and highly protective inner rust layer. A recent paper reports that the inner rust layer of the 3%-Ni weathering steel, considered responsible for its excellent weathering performance, which had been considered to be amorphous as a result of X-ray diffraction analyses, was found through electron beam diffraction analyses to consist of ultra fine magnetite (iron II and III oxides)[5].

4. Closing

This paper outlined the design philosophy of the chemical composition and the mechanism of the high weathering properties in high airborne salt environments of the 3%-Ni weathering steel having

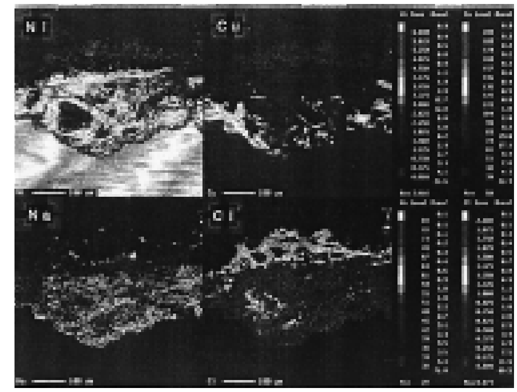


Fig. 6 Element distributions at section surface of rust formed on 3%-Ni weathering steel after 9-year exposure (Na and Cl separated and condensed in inner and outer layers, respectively)

enhanced salt corrosion resistance compared with conventional weathering steels. Peripheral application techniques such as service life estimation of structures made of conventional and developed weathering steels[20] and detail structural design technologies[21] for making the most of the characteristics of the developed weathering steel are expected to follow.

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