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Evaluation and classification of seawater corrosiveness by environmental factors*

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Abstract According to the data of main environmental factors and the depth of localized corrosion of carbon steel and low alloy steels in China seas, combined with the result of grey interrelation analysis, double-factor method was proposed to evaluate and classify seawater corrosiveness. According to the temperature of seawater and the biologically adhesive area on steels, the corrosiveness of seawater from low to high level is classified into five levels (C1–C5), which was identified by the data of corrosion depth of carbon steel immersed in water for one year.

Keywords: seawater corrosiveness, environmental factors, corrosion depth, corrosion evaluation and classification

1 INTRODUCTION

The corrosiveness in natural environment has been paid close attention for a long time. The evaluation of the corrosiveness in atmosphere and soil has been studied in detail, and the international standard ISO-9223 for classification of atmospheric corrosiveness has been established. Although the standard for evaluation of soil corrosiveness is more complex, it has been applied and improved (examples for DIN 50929 and ANSI A21.5). However, the evaluation of seawater corrosiveness is still under discussion. It is accepted that the corrosiveness of seawater actually depends upon all environmental factors, such as temperature, dissolved oxygen, saline degree and biological factors, etc. However, there exist key factors that essentially influence the corrosiveness of seawater. In tropical sea, the biological factors such as bacteria and algae adhesion on steels were thought as key factors (Jeffrey and Melchers, 2003).

According to the tests with three typical materials in 14 marine test sites from 1983 to 1988, Bopinder (1997) of ASTM concluded that the corrosion rate in long time exposure could not always represent seawater corrosiveness, and that the data of localized corrosion depth of steel exposed to the seawater were more important. They clarified the influence of marine environmental factors on corrosion at different test sites, but did not analyze statistically the marine environmental factors and evaluate seawater corrosiveness. European federation corrosion scientists studied the seawater corrosiveness around Europe with stainless steel, and tried to evaluate seawater corrosiveness, but they failed because of scattered data. In recent years, Chinese scientists studied the influences of seawater chemical composition on steel corrosion (Wang 1988; Hou 1999), analyzing the influence of the factors and steel chemical composition on corrosion using artificial neuro-network technique (Kong and Song, 1998). Carbon steel, low alloy steel and aluminum alloys were used by the authors to discuss the correlation of marine environmental factors and localized corrosion in seawater using grey interrelation analysis (Zhu and Zhang, 2000b; and Zhu, 2000). In the present paper, the following items were taken into account for the proposed preliminary program to evaluate and classify seawater corrosiveness in China marine areas using

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carbon steel and low-alloyed steel as test specimens: localized corrosion depth data in immersion test in various marine zones from north (Qinhuangdao) to south (Yongxing Island), environment factors of China marine zones, and the methods for evaluating seawater corrosiveness.

2 EXPERIMENTAL METHODS

Steel corrosion in marine environment is influenced significantly by marine corrosion environment factors such as seawater temperature, marine biofouling, dissolved oxygen, salinity, pH, flow velocity of seawater, as well as by internal factors (alloy composition) (Zhang et al., 2000). This research was conducted in different marine corrosion environment in China marine areas. Several one-year experiments on seven types of steels were conducted in temperate zone and meta-torrid zone in China seas. The selected metals were placed in full immersion in seawater in China marine areas for one year as per China GB 5779-86 standard to determine the localized corrosion depth of the selected metals. The chemical compositions of the test metals are listed in Table 1. Marine environmental factors were recorded including seawater temperature, dissolved oxygen, salinity, pH, flow velocity and the adhesion area of marine biofouling on the test metals in seawater.

Table 1 Chemical composition of test metals (wt. %)

Steel	C	Mn	S	P	Si	Ni	Cr	Mo	Al	Nb	V	Ti	Cu
Q235	0.20	0.55	0.009	0.015	0.26	-	-	<0.05	<0.03	-	<0.03	<0.03	<0.05
3C(j)	0.18	0.83	0.018	0.021	0.33	<0.10	<0.10	<0.05	<0.03	-	<0.03	<0.03	0.09
16Mn	0.16	1.40	0.025	0.009	0.36	-	<0.10	<0.05	<0.03	-	<0.03	<0.03	<0.05
15MnMoVN	0.19	1.52	0.004	0.026	0.40	-	<0.10	0.52	<0.03	-	0.15	<0.03	<0.05
D36	0.14	1.40	0.018	0.022	0.39	-	-	<0.05	0.025	0.03	<0.03	<0.02	<0.05
CF	0.08	1.32	0.004	0.014	0.43	<0.10	<0.10	0.05	<0.03	<0.01	<0.03	<0.02	0.07
09MnNb(j)	0.09	1.18	0.013	0.022	0.45	<0.10	<0.10	<0.05	0.05	0.037	<0.03	<0.03	0.07

Grey interrelation analysis was used to establish a correlation of marine environmental factors to localized corrosion depth of steel in seawater, and then use the seawater corrosiveness evaluation factors to evaluate seawater corrosiveness in different marine zones. The stronger the correlation is, the greater the influence of environmental factors on seawater corrosiveness is (Zhu, 2001).

3 RESULTS AND DISCUSSION

Environmental factors and their values in China marine areas are listed in Table 2, and the depth of localized corrosion of carbon steel and low-alloyed steels in full-immersion zone in China seas for one year are listed in Table 3.

Table 2 Environmental factors of differential marine zones in China (annual mean value)

Stations (zones)	Seawater temperature (℃)	Dissolved oxygen (ml/L)	Salinity	pH	Flow velocity (m/s)	Adhesion area of marine biofouling (%)
Qinhuangdao	12.5	5.6	30.5	8.10	0.01	90
Qingdao	13.6	5.6	32	8.16	0.1	50
Zhoushan	17.4	5.62	24.5	8.14	0.2	65
Xiamen	20.9	5.3	27	8.17	0.405	100
Beihai	23.8	5.19	27.9	8.05	0.01	100
Zhanjiang	22.3	5.06	32.6	8.15	---	100
Yulin	26.7	4.5	34	8.30	0.014	100
Xisha*	26.8	4.45	33.75	---	---	100

*Data at Yinggehai

Table 3 Data of localized corrosion depth on carbon steel and low-alloyed steel in full immersion zone in maritime China (mm)

	Qinhuang-dao	Qingdao	Zhoushan	Xiamen	Beihai	Zhan-jiang	Yulin	Xisha
Q235	0.42	0.41	0.59	0.65	0.68	(0.63)*	0.70	
3C(j)		0.29		0.77			0.84	(1.17)**
16Mn		0.34	0.37	0.74			1.10	
15MnMoVN		0.44	0.49	0.75			0.69	
D36		0.32		0.70			1.00	
CF		0.49		0.50			0.86	
09MnNb(j)		0.28		0.84			1.01	
Corrosiveness	C2	C2	C2	C3	C3	C3	C4	C4

*Results in different age. ** Results of sample on the ship.

3.1 Grey interrelation analysis

According to the theory of grey interrelation analysis, evaluation of seawater corrosiveness in marine zone depends not only on environmental factors but also on the correlation factor (f_i) to localized corrosion depth of steel. For this reason, a seawater corrosiveness evaluation factor is introduced as:

$$Q = \sum_{i=1}^{3}(Y_i \times f_i) \tag{1}$$

In which, Y_i is for three important environment factors (temperature, adhesion area of marine organisms and pH); and f_i is the correlation of three major environmental factors with corrosion depth. Product of Y_i and f_i can be used as classification for seawater corrosiveness of China marine areas. According to the analysis of grey interrelation, temperature and adhesion area of marine organisms were thought to be two major influential factors (Zhu and Zhang, 2000a).

3.2 Corrosiveness evaluation and classification of seawater of China marine areas

Test results were used to classify the corrosiveness of various marine areas into five levels based on mean localized corrosion depth of carbon steel of one-year experiment. Classification of seawater corrosiveness based on the depth of localized corrosion is listed in Table 4.

Table 4 Classification of seawater corrosiveness based on the depth of localized corrosion of steels

Mean localized corrosion depth (mm)	Corrosiveness	Corrosion level
≤0.25	Weak	C1
0.25–0.50	Moderately weak	C2
0.50–0.70	Medium	C3
0.70–1.00	Strong	C4
≥1.00	High	C5

The results of classification of seawater corrosiveness based on temperature and adhesion area of marine organisms are listed in Table 5, which is identified with the mean localized corrosion depth.

Table 5 Evaluation of seawater corrosiveness by two environment factors

Corrosiveness	Corrosion level	T (Temperature, ℃)	A (Adhesion area of marine organisms, %)	Equivalence in combination
Weak	C1	T1: <5	A1: <10	T1+A1-2
Moderately weak	C2	T2: 5–15	A2: 10–30	T2+A2-3
Medium	C3	T3: 15–25	A3: 30–50	T3+A3-4
Strong	C4	T4: 25–30	A4: 50–80	T4+A5
High	C5	T5: >30	A5: 80–100	T5+A5

Note: Temperature of seawater is the main environmental factor.

Having been shown in Table 3, the regional seawater corrosiveness levels in various Chinese marine zones should be: C2, Qinhuangdao, Qingdao and Zhoushan; C3, Xiamen, Beihai and Zhanjiang; C4, Yulin and Xisha. The result indicated the seawater corrosiveness can be effectively and readily assessed using double-factor method, which would yield the same result based on mean localized corrosion depth data.

Corrosion investigations on marine steel structures such as ships and platforms have indicated that more serious corrosion occurred in the South China Sea than in the East China Sea and Yellow Sea, which is similar to the statistical results of other outdoor tests in various marine areas. As corrosion is controlled by oxygen diffusion, at the same geographic zone, uniform corrosion to various steels is similar, while localized corrosion varied considerably. Therefore, localized corrosion depth data are objective in the evaluation seawater corrosiveness.

High temperature, high chloride content and low pH value increase the risk of localized corrosive attacks in any chloride-containing environment. Undoubtedly, temperature is usually the most influential factor. However, biological activities on steel surface are another agent of corrosion that must be considered. Since seawater, in other words, a living corrosive environment is sometimes difficult to be defined exactly what the service conditions would be. In normal seawater temperature, a biofilm would form on the steel surface and biofouling would occur on the surface of steels.

Marine biofouling usually has opposite influence on the localized and uniform corrosion. In seawater corrosion, marine biofouling can mitigate uniform corrosion rate, but aggravate localized corrosion. In southern sea areas, after one-year immersion in seawater, all the specimens were fouled by marine adhesion species (barnacles and mussels, etc), which blocked the entrance of oxygen, but the dead adhesion species can result in local acidifying, pitting could be initiated and propagated (Neville, 2000). In this case, uniform corrosion would be mitigated, while the depth of localized corrosion would be increased. The adhesion area of marine organisms is another major indicator in evaluation and classification of seawater corrosiveness.

In fact, conditions such as season, climate, geographical position, wave, ocean current, the property of materials and stress state, and so on can also affect seawater corrosiveness and become dominant factor(s) in certain circumstances. As a result, the method for evaluating seawater corrosiveness may vary.

Table 6 shows short period results compared with long period results in different sea area of China. It indicates that all the depth of localized corrosion exceeded 1 mm for different types of steels in the same or different sea areas after exposed for eight years or longer, so the present scheme of evaluation and classification of seawater

Table 6 Comparison of corrosion results in different length of time in different sea area of China (mm)

Materials	Year (s)	Qingdao	Zhoushan	Xiamen	Yulin
Q235	1	0.41	0.59	0.65	0.70
	8	1.14	1.14	1.15	1.40
	16	1.41	—	2.03	2.42
16Mn	1	0.34	0.39	0.74	1.10
	8	1.12	1.14	1.21	1.35
	16	1.37	—	1.06	2.18
3C(j)	1	0.29	—	0.77	0.84
	8	0.72	1.10(3Cw)	1.01	1.08
	16	1.04	—	1.46	1.20
15MnMovN	1	0.44	0.49	0.75	0.69
	8	0.92	—	0.99	1.39
	16	1.15	—	1.10	1.66

Note: Short bars mean no data available.

corrosiveness will be no longer suitable. This should mainly be due to the resistance of materials themselves. Similarly, just as the standard for classification of atmospheric corrosiveness, the present double-factor evaluation and classification of seawater corrosiveness is suitable only for shorter exposure period (one year). For longer exposure period, due to the resistance of materials, the difference of localized corrosion of materials in different sea areas would be smeared and that, the whole uniform corrosion rate would be very large. Thus, the present scheme is unsuitable in the evaluation for longer exposure test data.

4 CONCLUSIONS

The depth of localized corrosion of steel exposed for one year and marine environment factors are well correlated. Seawater temperature and adhesion area of marine organisms are two major marine environment factors. For China marine areas, based on the depth of localized corrosion of steels exposure for one year and the two major factors, the corrosiveness of seawater can be well classified into and evaluated on five corrosiveness levels.

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