Effect of alloy elements on the anti-corrosion properties of low alloy steel

BAORONG HOU*, YANTAO LI, YANXU LI and JINGLEI ZHANG

Institute of Oceanology, Chinese Academy of Sciences, Qingdao 266071

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Abstract. Effect of alloy elements on corrosion of low alloy steel was studied under simulated offshore conditions. The results showed that the elements Cu, P, Mo, W, V had evident effect on corrosion resistance in the atmosphere zone; Cu, P, V, Mo in the splash zone and Cr, Al, Mo in the submerged zone.

Keywords. Low alloy steel; anti-corrosion; electric connection.

1. Introduction

The anti-corrosion properties of steel in marine environment had long been studied, although there are only a few reported studies on the relationship between the anti-corrosion properties of steel and alloy elements. Ni–Cu–P anti-sea corrosion steel was first invented in 1951 in America. The result showed that the relationship between anti-corrosion properties of steel in marine environment and alloy elements was considerably different with variation of marine environment (Hou and Zhang 1980). The same alloy element's effect on the anti-corrosion properties of steel in the splash and immersion zones was also evidently different. The effects of alloy element on marine structures (such as oil-platform, steel-pile wharf, etc) in the sea mud zone, submerged zone, tidal zone, splash zone, and marine atmospheric zone were entirely different (Hou 1981). It was reported that a certain kind of alloy element can improve the corrosion resistance of steel in the splash zone, but not in the seawater zone, or even accelerate the corrosion rate there (Xia *et al* 1995).

To study the relationship between alloy elements and corrosion resistance of steel, 50 types of steels containing various elements were hung in the marine atmospheric zone, splash zone, tidal zone and seawater zone for 90 days to 2 years by the electric connection method. In this paper, only the effects of 18 alloy elements on the corrosion resistance of steel under the same conditions are discussed.

2. Materials and methods

2.1 Test equipment

The effect of alloy elements on steel corrosion in marine environment by using an experimental device and the

method of simulated corrosion of electrically connected specimen plates in the open sea is shown in figure 1 (The same fixing methods were applied to the 18 kinds of steels). The number 5 sample in figure 1 was the experimental sample. There were totally 10 samples in the marine atmospheric zone, splash zone, tidal zone and seawater zone. The specimens were connected with lead wires in order to simulate well the long-scale hanging plate.

2.2 Specimens

2.2a The sizes of specimens and their treatments: Before the test the 50 mm × 100 mm × 6.0 mm specimens were polished with No. 400 sandpaper, washed, degreased with alcohol, dried and weighed. After the test, the specimens were immersed in 20% HCl aqueous solution with 2% (CH)₂N₄ inhibitor to remove corrosion products, then washed, neutralized, and weighed to calculate corrosion rate.

2.2b Specimens installation: The specimens were installed vertically facing southward in plastic frames, as shown in figure 1, and were connected to each other with lead wires in order to simulate well the practical corrosion conditions in the open sea. The welding point was covered with epoxy resin to prevent corrosion due to contact with seawater.

2.3 Test period

Experiments on more than 50 kinds of low alloy steels were conducted by using a device for simulating the over-many-years-corrosion of electrically connected species in the open sea. The corrosion rates of different steels in 5 sections were tested, respectively. The test times were

*Author for correspondence

90 d, 180 d, 350 d, 2 y and 10 y, respectively. Results for 18 types of steels and 350 days of test time were selected to be analyzed in this paper. The chemical compositions of 18 types of steels are shown in figure 1.

3. Results and discussion

The respective corrosion rates of 18 types of steels in marine atmospheric zone, splash zone and seawater zone are given in figures 2–4. The corrosion rates of specimen 10 in the marine atmospheric zone are shown in figure 1. The corrosion rates of specimen 9 in figure 1 in the splash zone are shown in figure 3. The corrosion rates of the same steel in the seawater zone as shown in figure 4 are the average corrosion rates of specimens 1–5 in figure 1.

Figure 1. Experiment apparatus. (1. Test tank; 2. motor; 3. wave generator; 4. seawater; 5. electrically connected sample; 6. syphon tube (HTL: high tide level; LTL: low tide level)).

Figures 2–4 show that distinctly different carbon steel corrosion rates are mainly due to the different kinds and amounts of alloy elements added to carbon steel; and that the corrosion rates of the same steel in the marine atmospheric zone, splash zone and seawater zone also differed. For example, in the marine atmospheric zone (figure 2), the corrosion rates of 10CuPV steel and 1# steel were the lowest, about 0.05 mm/a; the corrosion rate of A₃ steel was the highest, about 0.25 mm/a, 5 times higher than the former. The corrosion rates differences were mainly due to the different kinds and amounts of alloy elements added to carbon steel.

In the splash zone (figure 3), the corrosion rate of 10CuPV steel was the lowest, 0.28 mm/a; the corrosion rate of 10Cr₂AlMo steel was the highest, 0.54 mm/a, 2 times higher than the former. The corrosion rates of 10Cr₂AlMoRe steel, 10CrAlMo steel, Sm41C steel, A₃ steel, 07SiAlV steel and 10PV steel were not much different.

Figure 2. Corrosion rate of 18 types of steels in atmosphere.

Table 1. Chemical contents of test steels.

No.	Steel	Mn	P	Si	Cr	Mo	Al	Cu	V
1	10MoWVRC	0.46	0.08	0.03		0.48			0.104
2	10MoWPC	0.47	0.102	0.125		0.46			0.122
3	16MnCu1.45	0.021	0.4				0.348		
4	17NiCuP	0.61	0.124	0.058				0.34	
5	15SiMoAl	1.44	0.018	0.57			0.2		
6	10CrAl	0.51	0.014	0.068	0.41		0.27	0.33	
7	10Cr ₂ AlMoRe	0.62	0.011	0.27	1.93	0.33	0.89	0.12	
8	10Cr ₂ AlMo	0.65	0.017	0.039	2.12	0.42	0.86	0.12	
9	SM41C	0.68	0.017	0.25					
10	A ₃	0.46	0.006	0.2					
11	10NiCuCrAlNb	1.09	0.047	0.45	0.62		0.27	0.35	
12	07SiAlV	0.56	0.017	0.435			0.78		0.15
13	10CrNbCu	0.4	0.116	0.047	0.29			0.1	
14	10PV	0.67	0.09	0.43					0.8
15	12CuPV	0.51	0.092	0.27				0.325	0.083
16	12MoPV	0.54	0.091	0.27		0.52			0.08
17	10CuPV	0.96	0.035	0.36			0.128	0.34	0.055
18	Steel No. 1	0.45	0.1	0.1	0.1			0.5	

In the seawater zone (figure 4), the corrosion resistance of 10Cr₂AlMoRe steel was the highest; its corrosion rate was 0.08 mm/a; the corrosion rate of A₃ steel was the highest, 0.265 mm/a, 3 times higher than the former.

Comparison of figures 2–4 shows that the corrosion rates of the same type of alloy steel in marine atmospheric zone, splash zone and seawater zone were different. The main corrosion rate of steels in the marine atmospheric zone was the lowest, that in the seawater zone was the second lowest. The corrosion rate of steel in the splash zone was the highest, usually 3–5 times higher than that in the marine atmospheric zone. Therefore, when the effects of alloy elements on the corrosion resistance of low alloy steel are studied, the different corrosion environments must also be considered.

The respective corrosion rates of three sample steels from the 18 different steels: A₃ steel, 10Cr₂AlMo steel and 17NiCuP steel, are shown in figures 5–7.

Figures 5 and 6 show that in the splash zone, the corrosion rates of 10Cr₂AlMo steel and A₃ steel had no obvious diffe-

rence, while in the seawater zone, the corrosion rate of A₃ steel was three to four times that of the 10Cr₂AlMo steel.

Figures 5 and 7 show that in the seawater zone, the corrosion rate of 17NiCuP steel (figure 7) was a little higher than that of the general carbon steel. In the splash zone, the corrosion of NiCuP steel was considerably lower than that of the general carbon steel (figure 5).

Figures 6 and 7 show that, in the seawater zone, the corrosion rates of 10Cr₂AlMo steel were lower than those of the 17NiCuP steel (figure 7). While in the splash zone, things changed radically, and the corrosion rates of 10Cr₂AlMo steel were higher than those of the 17NiCuP steel. (The reason has been discussed in another paper.)

The corrosion rates of the three steels in different environments show that different kinds and amounts of alloy elements added to carbon steel had distinctively different effects on the corrosion resistance of low alloy steel. The same alloy elements on the other hand, had different effects on the corrosion resistance of low alloy steel in different environments.

Figure 3. Corrosion rate of 18 types of steels in splash zone.

Figure 4. Corrosion rate of 18 types of steels in the immersion zone.

Figure 5. Corrosion rate of A₃ steel.

Figure 6. Corrosion rate of 10Cr₂AlMo steel.

Figure 7. Corrosion rate of 17NiCuP steel.

The relationship of the corrosion rate of low alloy steel in marine environment and the composition of alloy elements in the steel is fairly close, and cannot be described by a simple mathematical formula. A vast amount of test data was used to derive the following regression equations through regression analysis using computer (Xia *et al* 1995).

The regression equation for low alloy steel corrosion in the marine atmospheric zone was found to be

$$Y = 0.2281 - 0.059[\text{Mn}] - 0.2193[\text{P}] - 0.0336[\text{Si}] \\ + 0.00365[\text{Cr}] - 0.1548[\text{Mo}] - 0.0976[\text{Al}] \\ - 0.1787[\text{Cu}] + 0.0567[\text{V}],$$

where Y is corrosion rate and $[\text{Mn}]$, $[\text{P}]$, $[\text{Cr}]$, $[\text{Mo}]$, $[\text{Al}]$ stand for the amount of alloy elements used.

So, for steel in the marine atmospheric zone, the most effective alloy elements were P and Cu, the second most effective was Mo, but V was harmful. Adding V probably decreased the corrosion resistance of steel, but its effect was not obvious because the regression coefficient was only 0.0567. The regression equation for splash zone was as follows:

$$Y = 0.5613 - 0.0855[\text{Mn}] - 0.5214[\text{P}] + 0.0235[\text{Si}] \\ + 0.0751[\text{Cr}] - 0.2665[\text{Mo}] - 0.0185[\text{Al}] \\ - 0.2051[\text{Cu}] + 0.0561[\text{V}].$$

For steel in the splash zone, the most effective alloy elements were P, Mo and Cu.

The regression equation in seawater zone was as follows:

$$Y = 0.2297 - 0.0087[\text{Mn}] + 0.0047[\text{P}] + 0.0494[\text{Si}] \\ + 0.002[\text{Cu}] - 0.0267[\text{Mo}] - 0.1437[\text{Al}] \\ - 0.1117[\text{Cr}] + 0.0578[\text{V}].$$

For steel in the seawater zone, the most effective alloy elements were Al and Cr.

4. Conclusions

(I) The regression equations for low alloy steel corrosion in marine atmospheric zone, splash zone and seawater zone were established through regression analysis of the alloy elements and the corrosion resistances of steels using computer. The correctness of the results was 83%.

(II) Different alloy elements had different effects on the corrosion rate of steels in different marine environments. For example, the efficient anti-corrosion steels containing Cr and Al showed no evident corrosion resistance properties in the splash zone. So study of the effect of alloy elements on the corrosion resistance of low alloy steel must take into account the corrosive environments where they are used.

(III) The corrosion resistance of steel in the marine atmospheric zone was obviously increased by Cu, P and Mo; in the splash zone it was increased by P, Mo and Cu; in the seawater zone it was increased by Al and Cr in seawater zone.

(IV) Because of the limitations of the amount of different kinds of steels and testing time, the results of this test were not very satisfactory, so further research is still needed.

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