Study on corrosion simulation device for marine structural steel

HOU BAORONG* and XIANG BIN[†]

Institute of Oceanology, Chinese Academy of Sciences, Qingdao 266071, China

[†]Also at Graduate School of the Chinese Academy of Sciences, Beijing 100039, China

MS received 9 January 2003

Abstract. A corrosion simulation device was studied using offshore long scale hanging specimens. An Ni–Cu–P steel specimen was studied by analysing its corrosion products and corrosion types. The appearance of the samples and the surface of the metallic substrate after the removal of the rust layer produced by these two methods were observed and compared after 470 days of exposure. The phase structure of the corrosion products under different marine environments were analysed and compared. It further indicated good correlation between the electrically connected hanging specimen method and the long scale hanging specimen method.

Keywords. Corrosion simulation; marine structural steel.

1. Introduction

Electrically connected hanging specimens (ECHS) were used to simulate steel corrosion experiment in the study on the corrosion resistance of marine structural steels in marine environment (Baorong 1981; Baorong *et al* 2002). The results indicated that this method might be one of the best for marine corrosion simulation experiments. To further study this method using offshore long scale hanging specimens (LSHS), an Ni–Cu–P steel specimen was studied by analysing its corrosion products and corrosion types. The appearance of the samples and the surface of the metallic substrate after removal of the rust layer by these two methods were observed and compared after 470 days of exposure. The phase structure of the corrosion products under different marine environments was analysed and compared. It further indicated a good correlation between the electrically connected hanging specimen method and the long scale hanging specimen method.

2. Experimental

2.1 Materials

The material used was low alloy steel with chemical compositions as listed in table 1.

2.2 Offshore long scale hanging specimens

The steel samples were of 7 m long, 7 cm wide and 6 cm height. The top of the samples was in the atmosphere and

the bottom was totally immersed in seawater. The experiment site was the offshore platform of the Central Iron and Steel Research Institute, Qingdao Research Institute for Marine Corrosion, China.

2.3 Electrically connected hanging specimens

Experiments were done using the marine environment corrosion simulation device that was installed near the Qingdao offshore. The 100 mm long, 50 mm wide and 6 mm height steel samples were hung on a plastic testing rack. The samples were electrically connected with conductive wire. The samples were distributed in the atmospheric zone, splash zone, tidal zone and submerged zone for 470 days.

2.4 Treatment after experiment

First, photographs of these samples without any treatment at the end of the experiment were taken. Then, the outer rust layer was removed and IR analysis of the inner corrosion products was done. Finally, samples were rinsed with 20% hydrochloride acid + 1% hexamethylenetetramine to remove the corrosion products completely and then the surface of these metallic substrates was photographed.

3. Results

Figure 1 shows appearance of the steel samples after 470 days of exposure in the simulation device using the samples as electrically connected hanging specimens. Figure 2 shows appearance of the steel samples after 470 days of

*Author for correspondence

Table 1. Chemical compositions of Ni–Cu–P steel.

Elements	C	Si	Mn	S	Ni	Cu	P	Fe
Content (wt.%)	0.18	0.058	0.61	0.02	0.46	0.34	0.124	Rest

exposure using the offshore long scale hanging specimens. The IR analysis results on the rust layer accumulated on the electrically connected hanging specimens and the offshore long scale hanging specimens are shown in figures 3 and 4. The characteristic absorption wavelengths of some materials (Nyquist and Kagel 1971) are shown in these graphs and the arrow points to the strongest absorption peak. Figure 5 shows photographs of samples rinsed with acid metallic substrates of the electrically connected hanging specimens. Figure 6 shows photographs of the samples rinsed with acid metallic substrates of offshore long scale hanging specimens.

4. Discussion

4.1 Corrosion in marine atmospheric zone

The appearances of samples tested in marine atmosphere by the two methods were similar as could be observed from figures 1a and 2a. The rust layer of the tested low alloy steel in atmospheric zone was black and brown and a little dense. It could be seen that the inner rust layer was distributed completely on the substrate after removal of the outer rust layer. Compared with other zones, it was more difficult to remove the rust with acid from samples in atmospheric zone; which indicated that the corrosion product in atmospheric zone adhered tightly on the metallic substrate. IR analysis of the rust layer produced by the two methods in atmospheric zone yielded very similar results. Comparison of the corrosion products IR spectrum with IR spectrum of the standard showed that the main materials in corrosion products were **a**-FeOOH, **g**-FeOOH, **d**-FeOOH and $\text{FeO}_x(\text{OH})_{3-2x}$. In addition, corrosion in this zone was general corrosion without obvious local corrosion which occurred in the splash zone and submerged zone, as could be seen from figures 5a and 6a.

4.2 Corrosion in splash zone

It is well-known that corrosion in splash zone is the worst (Schumacher 1979), as could be observed in figures 1b and 2b. The results also were similar between electrically connected hanging specimens and offshore long scale hanging specimens. The rust layer in this zone was brownish yellow, a little thick, blistered in the outer part, irregular, and brittle, which was evidently different from that in the atmospheric zone. The IR analysis results were

Figure 1. Appearance of steels used as ECHS (470 d). a. Atmospheric zone; b. splash zone; c. tidal zone; d. submerged zone. **Figure 2.** Appearance of steels used as LSHS (470 d). a. Atmospheric zone; b. splash zone; c. tidal zone; d. submerged zone.

similar, too. The main materials of the corrosion products were **a**-FeOOH, $\text{FeO}_x(\text{OH})_{3-2x}$, **g**-FeOOH and **d**-FeOOH. The photographs of metallic substrates were similar between the two methods. The corrosion type was severe pitting corrosion that was different from that in the atmospheric zone.

4.3 Corrosion in tidal zone

In this zone, the appearances of the rust layer produced by the two methods were similar, too, as could be seen in figures 1c and 2c. The rust layer was thin and could be split, but there still was a piece of thin rust on the substrate. White spots of calcic and magnesian salt was easy to see in the rust layer. The IR analysis of the two methods' corrosion products yielded very similar results. The main materials were $\text{FeO}_x(\text{OH})_{3-2x}$, **b**-FeOOH, **g**-FeOOH, **a**-FeOOH, **d**-FeOOH. Corrosion types produced

Figure 3. Infrared spectrum of rusts on ECHS. a. Atmospheric zone; b. splash zone; c. tidal zone; d. submerged zone.

Figure 4. Infrared spectrum of rusts on LSHS. a. Atmospheric zone; b. splash zone; c. tidal zone; d. submerged zone.

Table 2. Corrosion results of the rust layers.

Zone	Rust appearance	Rust components	Corrosion type
Marine atmosphere zone	Brown and black, dense	a -FeOOH, g -FeOOH, d -FeOOH, $\text{FeO}_x(\text{OH})_{3-2x}$	General corrosion
Splash zone	Yellowish brown, thick, blister, irregular	a -FeOOH, $\text{FeO}_x(\text{OH})_{3-2x}$, g -FeOOH, d -FeOOH	Pitting corrosion
Tidal zone	Yellowish brown, thin, white spot	$\text{FeO}_x(\text{OH})_{3-2x}$, b -FeOOH, g -FeOOH, a -FeOOH, d -FeOOH	General corrosion
Submerged zone	Yellowish brown, very soft	b -FeOOH, g -FeOOH, Fe_3O_4 , d -FeOOH, $\text{FeO}_x(\text{OH})_{3-2x}$	Pitting corrosion

Figure 5. Photographs of metallic substrates of ECHS. a. Atmospheric zone; b. splash zone; c. tidal zone; d. submerged zone. **Figure 6.** Photographs of metallic substrates of LSHS. a. Atmospheric zone; b. splash zone; c. tidal zone; d. submerged zone.

in this zone by the two methods were both general corrosion, as could be observed in figures 5c and 6c.

4.4 Corrosion in submerged zone

Both rust layers produced in this zone by the two methods were brownish yellow, very soft, covering the sample surface like mud and very easy to remove, which was completely different from the rust in other zones. The IR result indicated that the main material was **b**-FeOOH. As seen from figures 5d and 6d, the corrosion types produced by both methods was characterized by severe pitting corrosion in this zone.

5. Conclusions

(I) Studies on Ni-Cu-P steel further indicated good correlation between the electrically connected hanging specimens method and the long scale hanging specimens method since the corrosion products and corrosion types of the two methods were similar in various environments. (II) The rust layer components, appearance and corrosion type of the Ni-Cu-P steel specimens after being tested in various marine environments in Qingdao were as given in table 2.

References

- Baorong Hou 1981 *Studia Marine Sinica* **18** 87
- Baorong Hou *et al* 2002 *Mater. Perf.* **42** 2
- Nyquist R A and Kagel R O 1971 *Infrared spectra of inorganic compounds* (New York: Academic Press) pp 218–219, 240–241
- Schumacher M 1979 *Seawater corrosion handbook* (New Jersey, USA: Noyes Data Corporation) p. 12