Accelerated Exposure Test for Corrosion of Steel and Its Welded Part under Water

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Abstract
Deterioration due to corrosion of steel bridge piers built the marine and coastal environment is a serious problem in the maintenance of steel bridges. For effective and rational maintenance of steel bridge piers, corrosion characteristics of submerged steel member should be investigated. In order to investigate corrosion characteristics of steel in the under-water environment, a standard method of an accelerated exposure test has been proposed by Japanese Society of Civil Engineers. In this study, for making the accelerated exposure test more efficient, a large size accelerated exposure test apparatus based on the standard one was newly developed. For verifying the performance of the new test apparatus, a series of tests on a typical structural steel was carried out. Furthermore, tests under the same conditions were performed on the fillet welded joints for examining corrosion characteristics of welded parts. As a result, scarcely any difference could be confirmed between corrosion characteristics of steel plates and welded parts. The corrosion rate by the test was 20 times as high as that of the actual underwater environment.
Keywords: Maintenance, Corrosion, Steel, Welded Joint, Accelerated Exposure Test

1. INTRODUCTION

Deterioration due to corrosion of steel structures such as bridge piers around the marine and coastal environment has become obvious. It is well known that the deterioration due to corrosion will become severer from now on. Replacing those damaged steel members with new ones is actually difficult because of its high cost and the recent sluggish economic situation in Japan. Therefore, it is important to use them as long as possible by performing repair, reinforcement and maintenance effectively [1].

For effective and rational maintenance of these steel structures under the corrosive environment, it is important to elucidate corrosion characteristics of steel in the under-water environment. In order to investigate and evaluate the corrosion characteristics of steel in the under-water environment, a standard method of an accelerated exposure test has been proposed by Japanese Society of Civil Engineers [2]. In this standard method, 16 steel plate specimens of 150×70×10 mm can be tested at once. For making the accelerated test apparatus more efficient, a large size accelerated exposure test apparatus based on the standard one was newly developed in this study. The size of the newly developed test apparatus was 6 times as large as the standard one. For verifying the performance of the newly developed test apparatus, a series of accelerated exposure tests on steel plate specimens were carried out. An average thickness reduction, a variation of corrosion depth and a corrosion rate by the newly developed test apparatus were examined.

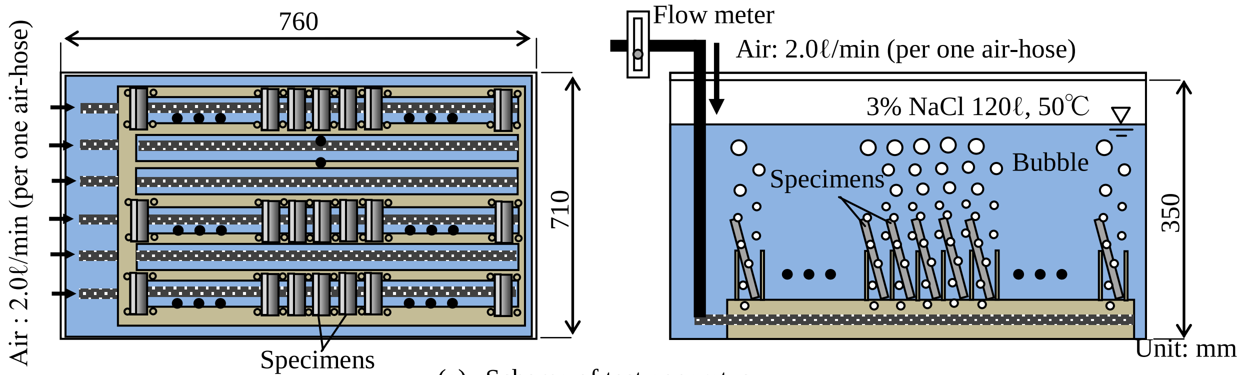
Welding is widely used for joining submerged steel members under water because of the water-tightness. It is obvious that geometric and material characteristics of welded parts are different from general parts of steel members, but the underwater corrosion characteristics of the welded parts are unknown. Therefore, a series of accelerated exposure tests on the welded specimens were carried out by the newly developed test apparatus. The underwater corrosion characteristics of welded parts under water were investigated by comparing with those of steel plates.

2. NEWLY DEVELOPED ACCELERATED EXPOSURE TEST APPARATUS

The newly developed test apparatus is shown in Fig. 1.

The dimensions of the test apparatus are 760×710×350mm. The test tank is filled with salt water (3%NaCl, 50℃, 120ℓ). Carbon steel specimens are set on acrylic stands at the bottom of the test apparatus. Air bubbles (2.0ℓ/min) are supplied from hosepipes set below the stands for generating the water flow and keeping the amount of dissolved oxygen. These conditions are kept during 28 days for accelerating the underwater corrosion of steel [2].

The size of the newly developed test apparatus is 6 times as large as that of the standard one [2]. In the new system, 96 specimens can be tested at one time at the maximum.



(a) Schema of test apparatus


(b) Exterior of experimental apparatus

Fig. 1 Newly developed test apparatus

3. PERFORMANCE VERIFICATION OF NEWLY DEVELOPED ACCELERATED EXPOSURE TEST APPARATUS

For verifying the performance of the newly developed test apparatus, a series of accelerated exposure tests on steel plate specimens were carried out. The material of specimens is a general structural steel (SM400) [3]. The dimensions of a specimen are 150×70×6 mm. For evaluating the corrosion from the one surface of each specimen that is directly subjected to the water flow and air bubbles from hosepipes at the bottom of the water tank, another surface and the edges of specimen are covered with anticorrosive coating.

Fig. 2 shows set positions of the specimens in the test apparatus. In the figure, red rectangles represent carbon steel specimens and white ones represent acrylic dummy specimens. Numbers of the carbon steel specimens and the acrylic dummy specimens are 24 and 72, respectively.

3.1. Thickness reduction

After the 28-days test, surface profiles of a specimen were measured by a laser displacement sensor.

Fig. 3 shows an example of surface profile of a specimen.

The degree of thickness reduction was found to vary in the same surface of one specimen. The average thickness reduction of all specimens obtained from the surface profile measurement is 0.27 mm.

3.2. Weight reduction

Fig. 4 shows a relation between the weight reduction and the set position of specimens.

Near the side walls of the test apparatus (y=35mm), the weight reduction of specimen was smaller compared with that near the central part of the water tank. The average weight reduction per specimen is 21.66 g. The standard deviation and the coefficient of variation area are 2.40 g and 11%, respectively. Weight reductions of all specimens are within about ±10 % of the average weight reduction.

In the past study where atmospheric corrosion characteristics of steel were examined by combined cyclic corrosion test using another accelerated exposure test apparatus [4], the coefficient of variation of the weight reduction is about 10%. Comparing the results by this test apparatus with that by the past study, the accuracy of this test result is quite same level with the past result. Furthermore, when the test results are evaluated by only the specimens enclosed by the blue dotted lines in Fig. 2, the coefficient of variation decreased to about 6% although the average weight reduction did not change much. To reduce a variation of results due to set positions, specimens in this region should be used for evaluation.

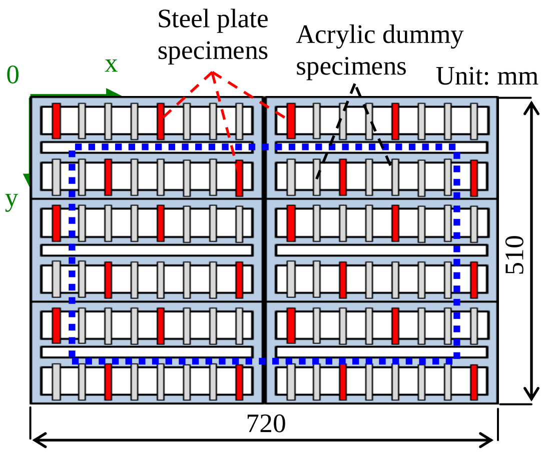


Fig.2 Set position of specimens

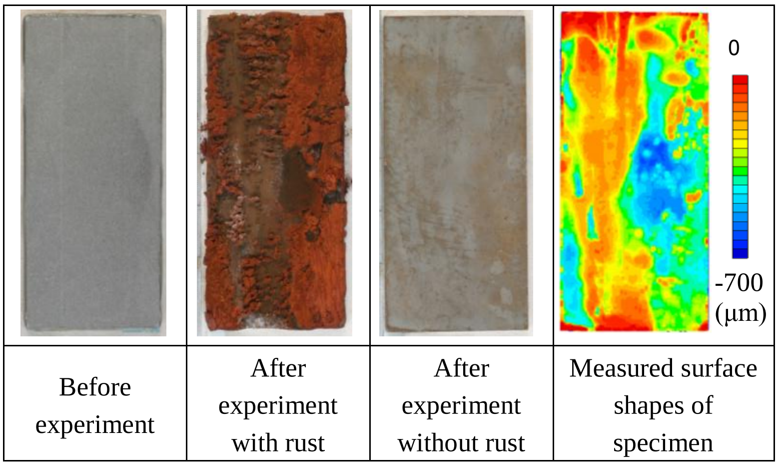


Fig.3 Example of surface shape of specimen

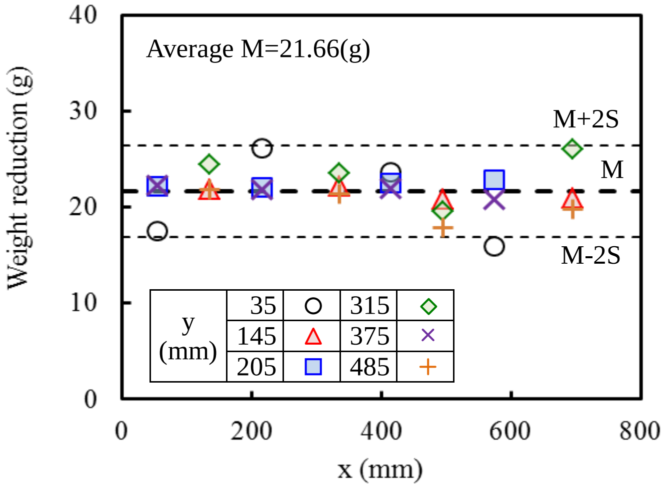


Fig.4 Relation between weight reduction and set position of specimens

3.3. Corrosion rate

The average thickness reduction calculated from the weight reduction of a 28-days test is 0.26 mm. This value is almost the same as the result obtained from the surface profile measurement (0.27 mm shown in 3.1.).

The corrosion rate is 3.45 mm/year, when converting the average thickness reduction for 28 days by this test into that for one year. In the field exposure test under the actual marine condition performed in the past research, the corrosion rate of steel plates in the tidal zone is about from 0.1 to 0.2 mm/year, the one in the submerged zone is about 0.2 mm/year [5]. It can be said that the corrosion rate by the newly developed accelerated exposure test apparatus is 20 times as high as that under the actual underwater environment.

4. CORRODION CHARACTERISTICS OF WELDED PARTS UNDER WATER

For investigating underwater corrosion characteristics of welded parts, accelerated exposure tests on welded specimens were carried out by the newly developed test apparatus.

Fig. 5 shows the shapes and the dimensions of specimens. They are made by cutting the tensile test specimens for the fillet weld joints specified in Japanese Industrial Standard (JIS) Z3131[6] and Z3132 [7] in the longitudinal direction and the thickness direction.

Table 1 shows a list of welded specimens. Eight types of specimens are examined where test parameters are the direction of welding (the longitudinal or the transverse), the material type of base metal (SY295 [8] or SYW295 [9]) and welding environment (in air or under water). The weld metal is the welding rod specified in Japanese Industrial Standard (JIS) E4319 [10], and the material of the cover plates is SM490.

To examine the influence of the set direction of specimens on the degree of corrosion, the two set directions shown in Fig. 6 are adopted in the test.

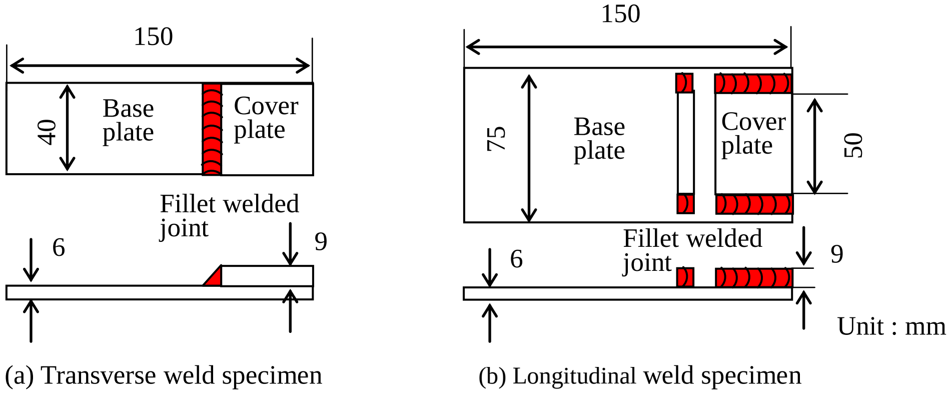


Fig. 5 Shapes and dimensions of fillet welded specimens.

Table 1 List of fillet welded joint specimens

Specimen designation	No. of specimens	Direction of welding	Base metal	Welding environments
TYA	3	Transverse	SY295	In air
TYW	3			Underwater
TWA	3		SYW295	In air
TWW	3			Underwater
LYA	4	Longitudinal	SY295	In air
LYW	3			Underwater
LWA	2		SYW295	In air
LWW	3			Underwater

4.1. Change of surface profile

After the 28-days test, the surface profile of each specimen was measured by a laser displacement sensor. Fig. 7 shows an example of the change of the surface profile of the welded part from that before the test. Surface property parameters of specimens specified in Japanese Industrial Standard (JIS) B0601 [11] were calculated from the measured surface profile data. The surface property parameters of the welded parts did not change significantly compared with those before the test. That is, the welded parts uniformly corroded from the surface regardless of the initial surface roughness.

4.2. Corrosion depth

In the region of 30 mm in length of the weld line direction, an average corrosion depth is calculated by dividing the amount of the change of the surface profile of weld bead by the surface area decided from the leg length. Fig. 8 shows the average corrosion depths of the specimens. In the figure, the average M and the ranges of the standard deviation S from the average (M±S) are presented.

The corrosion depth varied widely in the transverse weld specimens depending on the difference of set directions and weld environments, and a clear tendency was not confirmed. In the longitudinal weld specimens, variations of the corrosion depth were smaller compared with those of the transverse weld specimens. As a result, the average corrosion depth of the transverse weld specimens of downward set direction was 0.35 mm. That of the upward set direction was 0.25 mm. The average corrosion depth of all longitudinal weld specimens was 0.22 mm.

As a result of this test, the average corrosion depth of welded parts where any mechanical treatment was not applied on either the surface of weld beads or the toe was from 1.0 to 1.4 times as large as that of steel plate specimens. The same test has been carried out again in order to verify the difference between corrosion depth of steel plates and that of welded parts, the influence of the shapes of the specimens and the set direction.

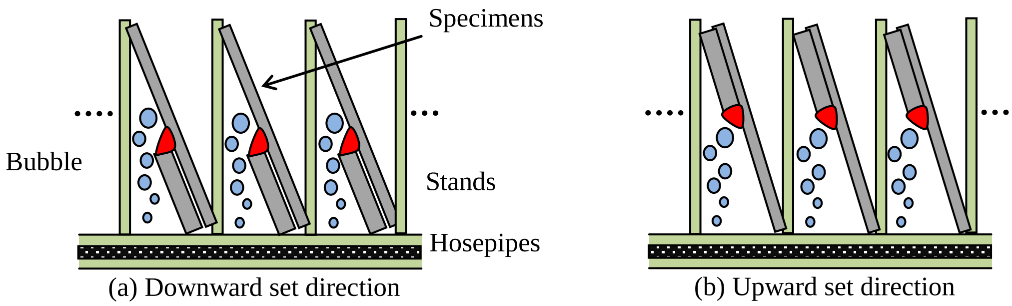


Fig. 6 Set directions of specimens

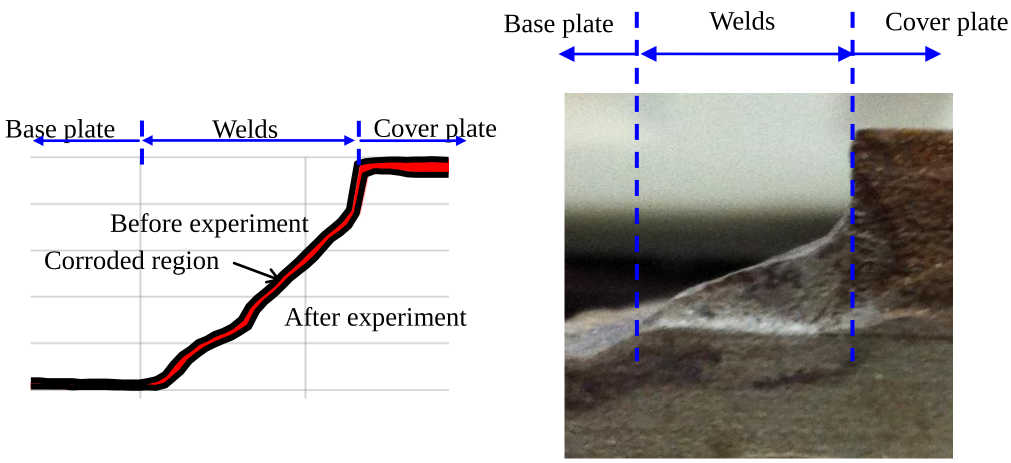


Fig. 7 Change of surface profile of welded parts due to corrosion (TYA3)

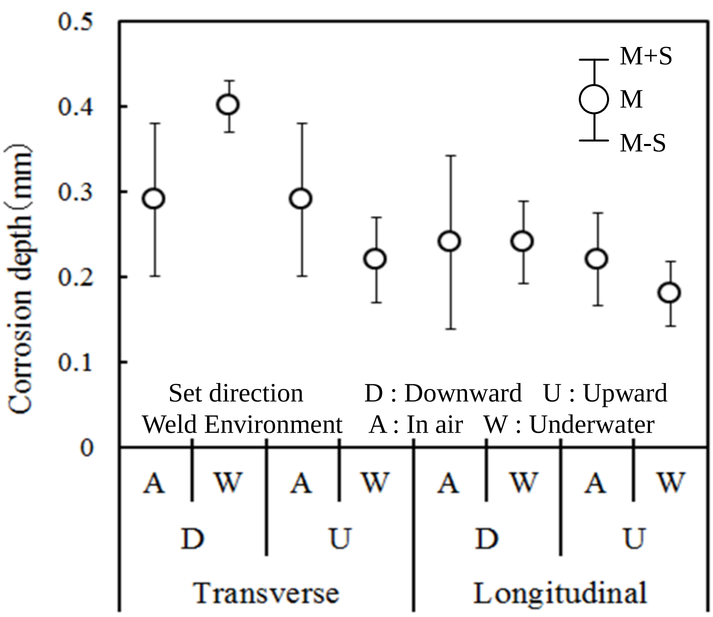


Fig. 8 Corrosion depth of welded parts

5. CONCLUTIONS

To make a more efficient accelerated exposure test method for underwater environment, a large size accelerated exposure test apparatus based on the standard one proposed by Japanese Society of Civil Engineers was newly developed. In order to verify the performance of the newly developed test apparatus, a series of accelerated exposure tests on steel plate specimens were carried out. Furthermore, accelerated exposure tests by using the developed apparatus were performed on the fillet welded joints for examining corrosion characteristics of welded parts.

Main conclusions obtained from this study are as follows

(1) The average thickness reduction of typical structural steel plates was 0.26mm after 28 days of test in the newly developed accelerated exposure test apparatus. The coefficient of variation due to the set position of specimens was 11%. Furthermore, the coefficient of variation was 6% when specimens placed by the side walls of the water tank were excluded from the evaluation.

(2) The corrosion rate converted from the weight reduction of steel plates resulting from the accelerated exposure test for 28 days was 3.45 mm/year. That was 20 times as high as that of the actual underwater marine environment.

(3) The surface roughness of welded parts did not change significantly compared with those before the test. The welded parts uniformly corroded from the surface regardless of the initial roughness of the surface.

(4) After a 28-days accelerated exposure test, the average corrosion depth of the transverse weld specimens set in the downward direction was 0.35 mm. The one set in the upward direction was 0.25 mm. The average corrosion depth of all longitudinal weld specimens was 0.22mm.

(5) The average corrosion depth of the welded parts where any mechanical treatment is not applied on either the surface of the weld beads or the toe was from 1.0 to 1.4 times as large as that of the normal steel plate specimens. The result indicated that welded parts might be easy to corrode slightly comparing steel plates.

6. PREFERENCE

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