

Effect of Water Chemistry on Flow Accelerated Corrosion of Carbon Steel

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1. Introduction

After the Surry Unit 2 accident in 1986, flow accelerated corrosion (FAC) has been extensively studied. However, many accidents caused by FAC have been reported, such as the accident at Mihama Unit 3 in 2004 and at domestic plants [1-3]. The mechanism of FAC is that a protective oxide layer on carbon steel dissolves into the flowing water, leading to a thinning of the oxide layer. As a result, severe failures occur in piping and equipment in nuclear power plants (NPPs). Numerous parameters such as geometry, pH, flow velocity, steam quality, dissolved oxygen (DO), temperature, and materials have an influence on FAC [4,5]. This paper describes the effect of dissolved oxygen on FAC of carbon steel at 150°C.

2. Methods and Results

2.1 FAC test loop development

We designed a small-scale FAC test loop and constructed it in order to test the carbon steel in an NPP environment, as shown in Fig. 1. This loop consists of a 1 gallon stainless steel autoclave with a magnetic driver, 100ℓ chemical makeup tank, high pressure pump, charging pump, pre-heater, cooling system, back-pressure regulator, ion exchange system, and many valves. Measuring instruments of DO, conductivity, pH, pressure, flow rate, and temperature were installed on the loop. Data acquisition system (DAS) and a UV/VIS spectrometer will be installed on the loop to perform the on-line monitoring of the above parameters and to measure the hydrazine concentration, respectively. As the loop is a recirculation system, the test solution circulates continuously through it.



Fig. 1. Photograph of FAC evaluation test loop.

2.2 Experimental

The chemical composition of the carbon steel (SA106 Gr. B) used for this study was as follows: C: 0.3, Mo: 0.15, Ni: 0.4, P: 0.035, Si: 0.1, Cr: 0.01, S: 0.035, Mn: 0.29, Cu: 0.4, V: 0.08 weight %. Test specimens were ring-typed tubes (61.52mm inner dia., 67.95mm external dia., 20.04mm height) made from a long pressure pipe; their inner surface made contact only with the flowing water. Two specimens were installed on the holder using bolts: one is for weight loss measurement and the other is for oxide layer analysis. We prepared 70ℓ of test solution using deionized water (>17 MΩ cm); the solution pH was not controlled. Before testing, solutions were deaerated with a high-purity (>99.999%) nitrogen gas for hours to adjust the DO content. The test conditions were as follows: 4 m/s flow velocity, 150°C, DO (<1 ppb, <1.3 ppm), 140 h duration, and neutral conditions. Monitoring of DO, conductivity, pH, flow velocity, and temperature were performed during the test period. The solution pH and DO content were measured using an in-line pH meter (METTLER TOLEDO, SWISS) and by an in-line DO meter (DO-32A, DKK-TOA, JAPAN), respectively. We will investigate the surface characteristics of the tested specimens with SEM/EDS and XRD.

2.3 Results of FAC tests

The DO concentration is a very important factor in the mitigation of FAC; however, the threshold oxygen content necessary to form a more protective oxide layer is not clear [4]. In this work, in order to determine the optimum oxygen concentration, first, we carried out preliminary tests on the FAC test loop with varying DO (<1 ppb, <1.3 ppm) content under neutral conditions. The DO content was well controlled throughout the test period, as shown in Fig. 2. After 20 h, the concentration of DO was stabilized. For test 1 (DO<1ppb), the oxygen-free condition, the pH values increased from 6.5 to 8.2 for 24 h and then stabilized at 8.5, which value is much higher than the initial neutral pH value of 6.5. For test 2 (DO<1.3ppm), the very high oxygen concentration condition, solution pH values were in the pH range of 6.7-7.5. The above results are not consistent with other data by Lee et al., who reported that the solution pH was drastically increased as the iron oxidation reaction occurs [2]. In our test 2, the solution

pH values were low compared to those of test 1, regardless of the much higher DO concentration.

After 140 h exposure during test 1 and test 2, the specimens were withdrawn for examination. Their surfaces changed to a black color, typical of magnetite. We dried the specimens in a 100°C oven in a vacuum for 24 h and then sonicated them in acetone for 5 min. The weight loss values of the specimens for test 1 and for test 2 were 10 mg and 20 mg, respectively, which is indicative of non-adherent oxides. This is confirmed by the followings. The weight loss decreases with an increase in the pH range of 7.0-9.0 due to the magnetite solubility effect on pH [1].

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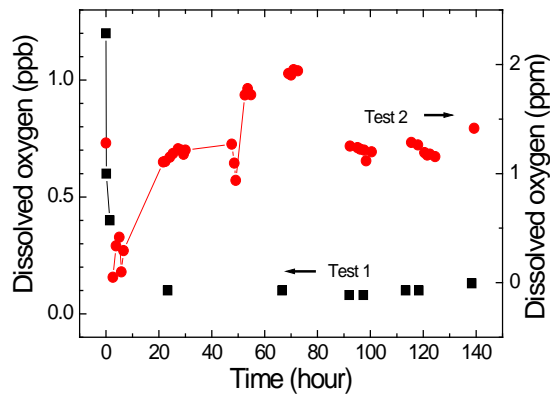


Fig. 2. Monitoring results of dissolved oxygen concentration.

3. Conclusions

A small-scale FAC test loop was designed and constructed to test carbon steel in an NPP environment. In order to determine the optimum oxygen concentration, first, we carried out two preliminary tests on the FAC test loop with oxygen-deficient (DO<1ppb) and high oxygen (DO<1.3ppm) condition. The weight loss of the specimens increased with increase of the DO content and decrease of the pH in the test solution. More tests will be conducted to determine the optimum oxygen concentration.

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