Integrated Approach to Monitor Flow Accelerated Corrosion

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1. Introduction

Aged nuclear piping has been reported to undergo corrosion-induced accelerated failures, often without giving signatures to current inspection campaigns. Flow Accelerated Corrosion (FAC), one of the hot issues in aged piping occurs due to many combined parameters. Therefore, we need to monitor as many parameters as possible, and that cover wide area, since we don't know where the FAC occurs. Therefore, we need diverse sensors which can cover wide area in the on-line application.

Since FAC is a combined phenomenon, we reviewed parameters important to FAC occurrence, and then surveyed applicable sensors. First, we identified feasibility by analytical way, and then we developed electrochemical sensors for high temperature application. We also introduced mechanical monitoring system, which gathers thickness-dependent signals. These signals are indirect, and thus we need an interface which converts monitored results to an identical parameter. We introduced wearing rate model, which accepts the electrochemical parameters as inputs. By the model, we can predict the wearing rate and then we can compare the monitored electrochemical parameters with the thickness monitoring result as a validation. After the preliminary tests, we developed the FAC simulation test loop of high temperature and pressure, which is similar to the secondary part of the NPP. We changed pH and dissolved oxygen of the developed test loop to accelerate FAC. To support the validation of the monitored results, we also adopted high temperature UT, which shows good resolution in the testing environment. By this way, all the monitored results can be compared in terms of thickness.

2. Development of Integrated Monitoring Framework

2.1 Developed Diverse Sensors

In the FAC monitoring, water chemistry (pH, dissolved oxygen) is an important parameter to evaluate FAC susceptibility. In this work, we concentrate on detecting electrochemical parameters of the target system. Electrodes for high temperatures are developed and pre-tested. [1]

We assumed that the vibration mode would change with the reduction of the weight and the change of inner profile of the piping. We preliminarily analyzed the vibration mode change with thickness using Finite Element Method (FEM). It showed expected vibration mode shift. Based on the results, we surveyed various displacement and acceleration sensors. We chose fiber-optic displacement sensors, capacitive sensors and fiber optic accelerometers and 3-axis accelerometers. We tested chosen sensors with different thickness piping. As results, we found 3-axis accelerometer would be the most suitable for the FAC test environment. [2]

To validate monitoring results of developed sensors, direct measurement of piping thickness is required. Thus, we chose an Ultrasonic Transducer (UT) for high temperature application for this purpose and pre-tested for the feasibility.

2.2 Wearing Rate Model

Electrochemical parameters such as pH, and dissolved oxygen as well as temperature, which highly affect the FAC, are not quantifiable. Therefore, we introduced wearing rate model to convert monitored variables to thickness information to compare monitoring results from different sensors.

To predict the thickness of the piping by FAC, we introduced a wearing rate model and then modified it considering the test condition. Sanchez-Caldera's Model is a theoretical model that can predict the rate of materials reduction induced by FAC, which is shown in the equation (1). [3]

$$\frac{dm}{dt} = k_g \frac{\theta(C_e - C_\infty)}{\frac{1}{k} + (1-f)\left[\frac{1}{h_D} + \frac{\delta}{D}\right]} \quad \text{..............} \quad (1)$$

2.3 Validation Test

In this work, we designed the test loop to accelerate the FAC to induce continuous thickness change. By simulation test, we expect to identify on-line applicability of sensors. Test conditions are chosen to accelerate degradation. Test temperature was 125°C, flow velocity is 3 m/s and pressure is 20 bars. pH was chosen to low level with dissolved hydrogen as 150 ppb based on the wearing rate model. FAC is also affected by geometrical feature. We chose piping elbow as a testing target, which is known to the most FAC-affected region. Testing material is made of carbon steel. Figure 1 shows the overall structure of the simulation test loop.

Figure 1 FAC simulation test loop

2.4 Test results and Discussion

Monitoring results of electrochemical parameters showed that the test condition was maintained in the corrosive region of the ECP-pH diagram. Vibration monitoring results showed no clear evidence of mode shift according to the thickness change. Therefore, we need different signal processing method and additional tests. Figure 2 shows the degraded inner surface of the elbow specimen.

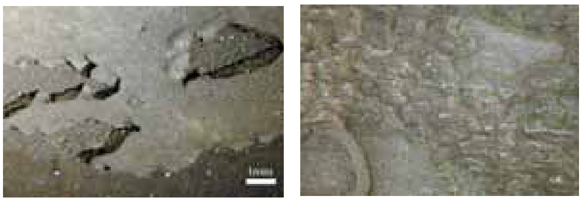

Figure 2 Inner surface of the elbow specimen

Figure 3 shows the calculation result of the Sanchez-Caldera's model, UT monitoring result and monitored pH.

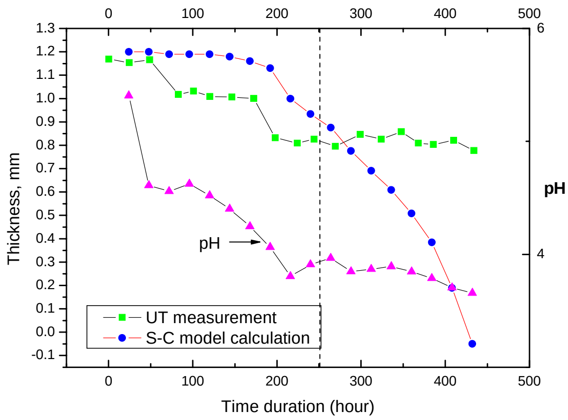

Figure 3 Comparison between monitored thickness and prediction model

Before 250 hour, it shows the similar trend of thickness reduction due to low pH. After 250 hours of operation, however, measured and predicted values show difference. The model shows continued reduction, whereas UT monitored result shows no reduction afterwards. According to the model, piping should be penetrated, which is not. In the equation (1), we assumed C_∞ as negligible. When the FAC rate is increased, ions in the bulk water will increase. It means that C_∞ is no more negligible. As time passed, ion concentration in the bulk water will build up until close to C_e, which will mitigate the reduction rate

3. Summary and Future Work

In summary, the objectives and what we did in this work are listed as below:

1. Identify sensor applicability to high temperature and on-the-pipe installation and performance to monitor the FAC environmental status or thickness identification.
2. Construct FAC test loop for the validation of sensors: Design electrochemical environment and induce more than 10% of thinning of the target piping, which corresponds to the resolution target of sensors.
3. Validate FAC wearing rate model with monitored parameters. Using wearing rate model, thickness can be calculated with monitoring parameters. We can compare the predicted values with UT measuring result to validate the monitoring results.

Test results show that the approach suggested in this work is promising. As a future work, we are working on the development of direct thickness measurement system, Direct Current Potential Drop (DCPD) method for the high temperature application.

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