Verifications of ES-DCPD method for piping wall thickness monitoring in the SFASL

Kyung Ha Ryu [a*], Ji Hak Kim [a], Il Soon Hwang [a]
[a] *Seoul National University, Seoul National University, Bd. 31-1, 56-1 Shinlim-dong, Gwanak-ku, Seoul, 151-742, Korea*
[*] *Corresponding author: future1@snu.ac.kr*

1. Introduction

Although various monitoring systems, algorithm and the concept of redundant systems were developed for nuclear power plant's (NPP) aged components, accidents in NPPs have been reported continuously such as Surry unit-2 flow accelerated corrosion (FAC) accident and Mihama unit-3 FAC accident. We developed a new piping wall loss monitoring system using equipotential switching direct current potential drop (ES-DCPD) method [1, 2]. This method can be used as a screening method with high speed, thus can also be used as a precise online monitoring method. This method has been developed and planned for a demonstration to a NPP's secondary side piping system in Korea.

2. ES-DCPD Method for Monitoring Piping Wall Loss Monitoring

The direct current potential drop (DCPD) method is a traditional method to inspect material properties especially online cracks length monitoring. To apply this method to inspection of NPP's piping wall loss, ES-DCPD method was developed. To prevent external current leakage, equipotential method was developed by installing two independent current sources with circuits, and by synchronizing its current switching. By maintaining both ends as equipotential, it was possible to achieve zero current flows outside of the target monitoring range and thus no sensor interferences during the inspection [1]. By synchronized switching current, thermoelectric noises were eliminated and thus standard deviations of signal decreased more than quadruple in the traditional DCPD method [2].

2. Experimental Procedure

In the real plant environment, FAC rate is only a few. FAC makes slow progress over several decades. To produce and test the FAC process in the laboratory, it is essential to accelerate FAC rate.

FAC rate is increased with following factors: higher flow velocity, lower presence of chromium, copper, and molybdenum in the pipe's material, temperature near about 150°C, lower dissolved oxygen (DO), higher dissolved hydrogen (DH) in the case of DH is 0~150 ppb range [3]. To reflect the real NPP water chemistry and accelerate the FAC rate, adopted test condition shown in Table I. This water chemistry aims to reflect the condition of Reheater drain line of Yeounggwang unit 3 NPP in Korea. The test specimen is ASTM A106 Grade B carbon steel, which has low chrome contents. To accelerate FAC in the acid environment, ferrous ions were accumulated, which makes stable species of iron magnetite. X-ray diffraction (XRD) test result after test guaranteed this concept.

TABLE I: Test Conditions

	SFASL-2007	SFASL-2008
Geometry	90° Elbow (R/D*: 1.5)	90° Elbow*
Cr, Mo, Cu contents	Under 0.1	Under 0.1
Fluid velocity	~ 5m/s	~ 5m/s
DO (ppb)	Under 5	Under 5
DH (ppb)	~ 150	~ 150
Contents of Cr, Mo (%)	Under 0.1	Under 0.1
Temperature	130°C, 150°C	145°C, unsteady simulation (135°C ~140°C), 150°C
pH	~4.1, ~3.5, ~3.0 (changed) and one-step alkaline condition	~5.0 (fixed) and two-steps alkaline conditions

*R/D means the curvature of elbow.

3. Experimental results and Discussion

3.1 Monitored water chemistry

Various parameters were monitored such as flow velocity, DO, DH, inlet pH, pH and electrochemical potential (ECP) at the test specimen, and so on. Measured ECP and pH are plotted in the ECP-pH diagram as shown in Figure 1. ECP and pH moves along almost linear behaviors. The relation is as follows. In the case of SFASL-2007 test, ECP = 0.0009–0.0665pH. In the case of SFASL-2008 test, ECP = 0.0030–0.074pH. These results showed that simulation tests were successfully performed reflecting NPP's environments.

3.2 Wall Thinning Simulation Results

After SFASL-2007 and SFASL-2008 experiments, destructive test was performed. Figure 2 shows inner surface of the specimen. The inner surface showed clear evidence of FAC. An orange-peel appearance was observed, which represents general FAC morphology.

The major thinning in the SFASL-2007 test was occurred at the former region of welding part in the elbow's outlet side. There was just a little wall loss in extrados of the elbow. This shows that the local fluid disturbance was generated by welding bead, rather by elbow geometry. Because the piping size used in this experiment is small, 2.5 inches diameter, we think some of the welding bead gave a big impact compared to big size pipe's case. In the case of SFASL-2008, major thinning area was observed in outlet straight pipe sections. There was almost no thinning in the elbow part. We think this result reflects the impact of welding bead or high fluid velocity effect.

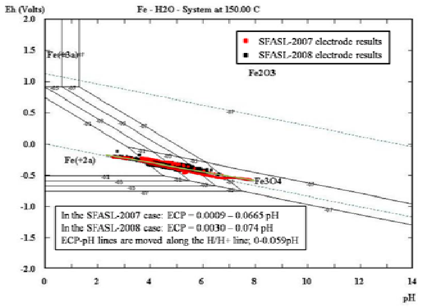
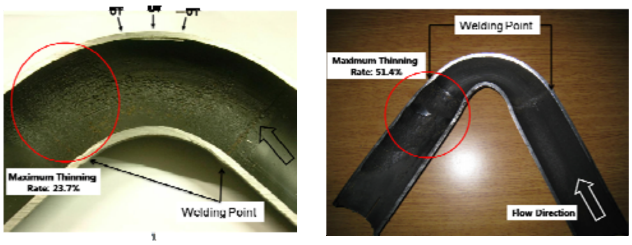


Figure 1. Measured ECP and pH at the carbon steel specimen

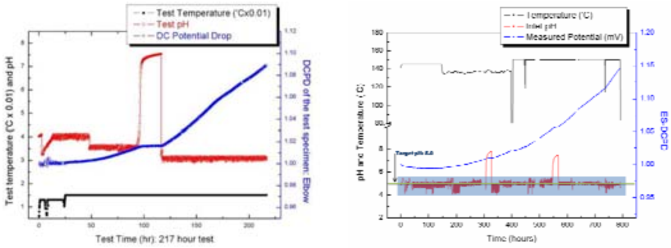


(a) (b)

Figure 2. Destructive test result: Inner Surface (a) SFASL-2007 (b) SFASL-2008

3.2 Wall Loss Monitoring Results

Figure 3 (a) shows the ES-DCPD result of SFASL-2007. The change of ES-DCPD is increased with the temperature because FAC is more vigorous near 150°C than that of 130°C. Decreasing pH leads fast the change of ES-DCPD. As a confirming test, we made the pH increase to alkaline condition. In this case, the change of ES-DCPD is almost zero, which shows that ES-DCPD describe FAC well. ES-DCPD shows the change of 9% which recorded the maximum thinning rate of 23.7%. ES-DCPD of SFASL experiment in 2008 is represented in Figure 3 (b). ES-DCPD shows the trend of continuous increase because of steady state pH. In the ES-DCPD confirming test, increasing pH to alkaline condition resulted remarkable decrease of ES-DCPD change. Temperature normalization capacity of ES-DPCD is also described in Figure 3 (b). After 147 hrs, temperature dropped 10°C and maintained unsteady state between 135°C and 140°C. ES-DCPD shows the trend of continuous increase regardless of temperature changes. Finally, ES-DCPD increased to 14.7% and maximum wear rate is about 51.4%.



(a) (b)

Figure 3. ES-DCPD result (a) SFASL-2007 (b) SFASL-2008

In SFASL-2007 test, thickness measurement was performed at three points using by UT during the test. UT inspection points are marked in Figure 2 (a). However, online UT inspection did almost not detect wall thinning. In general case, a spot of maximum FAC rate is extrados of elbow. However in this experiment, FAC was occurred at the front and rear of welding area. In case of SFASL-2008 experiment, thickness measurement by UT was performed at 12 point in the elbow. Likewise, thickness changes weren't detected. In this experiment, wall loss was occurred at straight pipe passed by elbow. These errors of UT measurement show the benefit of online application of ES-DCPD. Although online UT is adopted to monitor CANDU feeder line, online UT has limitations by its point detection method. Unless we know the point of maximum thinning, the efficiency of online UT is depreciated. On the other hand, ES-DCPD can inspect wider areas at once time. ES-DCPD also has a good ability for applications in high temperature and high radiation region.

3. Conclusions

ES-DCPD method was introduced for wall loss monitoring. FAC accelerated simulation test were performed in SFASL to verify this method. ES-DCPD is being developed targeting NPP's piping system. After the successful development in NPP's system, spread applications to various fields may be possible.

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