Surface coatings on carbon steel for prevention of flow accelerated corrosion under two-phase flow conditions

Hee-Sang Shim[a,*], Kyung Mo Kim[a], Seung Hyun Kim[b], Ji Hyun Kim[b], Do Haeng Hur[a]
[a]*Division of Nuclear Materials Development, KAERI, 989-111 Daedeok-daero, Yuseong, Daejeon 305-353, Korea*
[b]*School of Mechanical and Nuclear Engineering, Ulsan National Institute of Science and Technology, 100 Banyeon-ri, Eonyang-eup, Ulju-gun, Ulsan 689-798, Korea*
[*]*Corresponding author: hshim@kaeri.re.kr*

1. Introduction

Flow accelerated corrosion (FAC) is a phenomenon that affects the normally protective oxide layer formed on carbon steel as a piping materials of nuclear power plants [1,2]. The oxide layer dissolves into the flowing steam of water or a water-vapor mixture with FAC and the protective oxide layer becomes thinner along with increase of corrosion rate. Consequentially, the integrity of the piping materials is treated when the dissolution rate reaches to the corrosion rate. Moreover, iron-based corrosion products, which are produced with FAC, become a main source for various corrosion phenomena of steam generator tubes as transported to steam generator.

Since the occurrence of a Surry-2 pipe rupture accident, a lot of effort has been made to prevent FAC of carbon steel piping. Some of the chemicals were suggested as a corrosion inhibitor [3,4]. A platinum decoration was applied as another prevention strategy of carbon steel thinning [5]. The severe FAC-damaged carbon steel pipings were replaced by tolerant materials such as SA335 Gr.P22. However, some components such as the piping materials between moisture separator and turbine have still suffered from the FAC degradation.

This work provides a coating method to prevent the FAC degradation of the SA106 Gr.B, which is a piping material between moisture separator and high-pressure turbine, under two-phase flow.

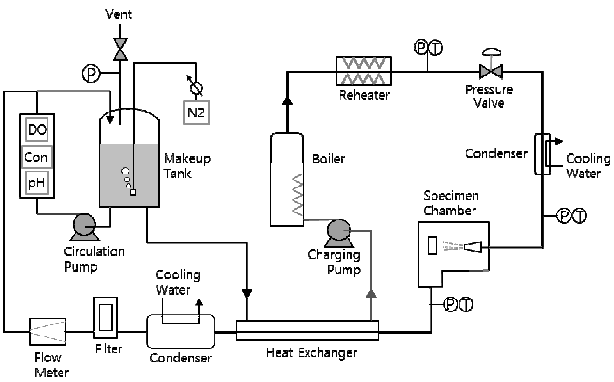

Fig. 1. Schematic drawing of two-phase FAC test loop.

2. Methods and Results

2.1 FAC prevention coatings

A lot of coating materials were considered in order to prevent two-phase FAC of SA106Gr.B in this work. Fe-W-Cr alloy, Ni-P and Ni-P-TiO_2 were selected finally as a coating material through literature survey. Fe-W-Cr was coated using high velocity oxy-fuel thermal spray method [6] and, Ni-P and Ni-P-TiO_2 were deposited through electroless coating method [7] on the SA106Gr.B, respectively. FAC test specimens were prepared in an area of 20 mm x 20 mm with a 2 mm thickness.

2.2 Tow-phase FAC test

Experiments were conducted using a simulated wet-steam FAC loop schematically shown in Fig.1 for 240 h, which consists of a steam boiler, reheater, test chamber, heat exchanger and solution tank. Dry steam was provided by reheating the steam produced at steam boiler. The steam quality and velocity in test chamber were controlled to 85% and 37 m/s using pressure control valve and heat exchanger. The steam injected into test chamber was cooled down to liquid, passing through a condenser and traveled to solution tank of 100 L. The pH and dissolved oxygen concentration were maintained at 9.5 and less than 10 ppb, respectively, during the test.

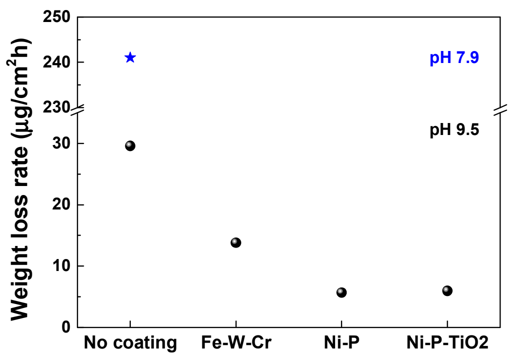

Fig. 2. Weight loss rate of SA106 Gr. B with or without protective coating at 150°C in pH9.5.

Fig. 2 shows weight loss per unit area and time due to two-phase FAC degradation for non-coated and coated SA106Gr.B specimens at pH 9.5. The SA106Gr.B presents a large weight loss of 2 times and 5 times compared to the SA106Gr.B coated with Fe-W-Cr and Ni-P protecting layer. In addition, the weight loss of SA106Gr.B under pH 7.9 reveals higher value by 7 times than that under 9.5. This result is corresponded with the surface pictures as shown in Fig. 3.

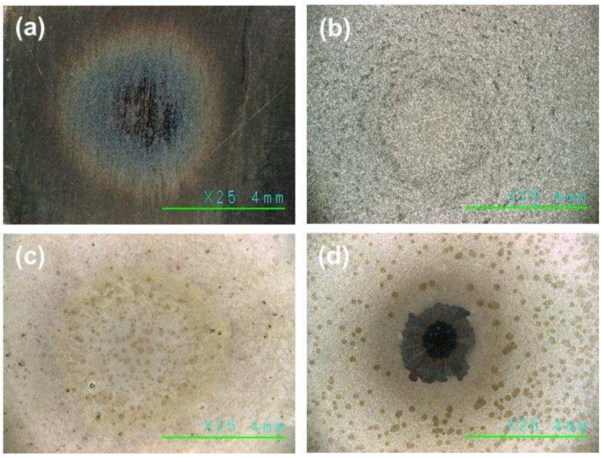

Fig. 3. Stereoscopic pictures of carbon steel specimens with protective coatings; (a) as-received SA106 Gr.B, (b)Fe-W-Cr coated, (c)Ni-P coated and (d) Ni-P-TiO_2 coated SA106Gr.B.

Fig. 3 shows the surface photos of the specimens tested under steam quality of 85 % at 150^{o}C and 3.8 bar. The SA106Gr.B as a reference specimen presents clear creator with a diameter of ca. 6 mm, but other specimens didn't show a volumetric loss. In particular, the specimen coated with Ni-P shows no damage under two-phase steam flow. Other coated specimens reveal only faint traces for wet-steam impingement or stains.

3. Conclusions

We suggested the coating materials to prevent FAC of SA106Gr.B under two-phase water-vapor flow. The FAC resistance of SA106Gr.B was improved with 5 times by electroless-deposited Ni-P protective layer. Other coating materials also enhanced the tolerance up to 5 times for the FAC in a condition of 150 ^{o}C and 3.8 bar at 9.5 compared to non-coated SA106Gr.B.

Acknowledgements

This work was supported by the Nuclear Power Core Technology Development Program of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) granted financial resource from the Ministry of Trade, Industry & Energy, Republic of Korea (2013T100100029).

REFERENCES

[1] K. Fruzzetti, Multivariable Assessment of Flow Accelerated Corrosion and Steam Generator Fouling, EPRI Report 1003619, Palo Alto, CA; Electric Power Research Institute, 2003.

[2] W. Ahmed, M. Bello, M. Nakla, A. Sarkhi, H. Badr, Experimental investigation of flow accelerated corrosion under two-phase flow conditions, Nucl. Eng. Des., 267(2014) 34-43.

[3] R. Bateman, W. Cook, M. Dymarski, D. H. Lister, F. Steward, The Possible Inhibition of Feeder Thinning by Titanium Dosing, 23rd Annual CNS Conference, Toronto, Canada, June 2-5, 2002.

[4] U. C. Kim, K. M. Kim, and E. H. Lee, Effects of Chemical Compounds on the Stress Corrosion Cracking of Steam Generator Tubing Materials in a Caustic Solution, Proc. Int. Conf. Water Chem. Nucl. Reactor Systems, San Francisco, CA, EPRI, 2004.

[5] Y. J. Kim, Effect of Water Chemistry on Corrosion Behavior of 304 SS in 288^{o}C Water, Int. Conf. on Water Chemistry of Nuclear Reactor Systems, 3-2, San Francisco, CA, EPRI, 2004.

[6] Z. Zheng, Y. Zheng, W. Sun, J. Wang, Erosion-corrosion of HVOF-sprayed Fe-based amorphous metallic coating under impingement by a sand-containing NaCl solution, Corr. Sci. 76(2013) 337-347.

[7] H. Liu, S. Bi, L. Cao, Q. Bai, X. Teng, Y. Yu, The Deposition Process and the Properties of Direct Electroless Nickel-Phosphorous Coating with Chromium-Free Phosphate Pickling Pretreatment on AZ31 Magnesium Alloy, Int. J. Elechem. Sci., 7(2012) 833-8355.