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Effect of surface stress states on the corrosion behavior of Alloy 690

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1. Introduction

The Alloy 600 SG tube material has been replaced to Alloy 690 being more resistant to stress corrosion cracking. However, the metal cation released from surface might be accumulated in primary circuit for its long operation times, and any other unknown manufacturing processes may affect the integrity of the Alloy 690 surface property [1]. Clauzel et al. have observed the corrosion behavior of Alloy 690 manufactured from various suppliers and classified the tubes regarding their metallurgical properties, release and corrosion with relation of microstructure, surface pollutions, microhardness, roughness and carbon content [2]. Guinard [3] and Huang [4] have studied the roles of surface state conditions, cold-work, and electropolishing of Alloy 690 on corrosion release rate. There are many studies on the metal surface improvement using electropolishing and shot peening methods.

The corrosion rate of electro-polished stainless steel was lowered by more than a factor of three relative to that of machined surfaces in mild alkaline, hydrogenated water at 260 ^{o}C, and this reduction was explained by a decrease in surface microstrain. It was known that the higher equilibrium Cr concentration of Alloy 690TT results in a good resistance to intergranular attack (IGA) and stress corrosion cracking (SCC) failures in high temperature water environments [5]. Zhang et al. reported that the stress corrosion cracking (SCC) of Alloy 690TT was reduced by shot peening and electropolishing treatments [6]. Some studies also showed that the compressive residual stresses serve to inhibit the initiation of SCC [7, 8]. However, it had not been clearly evaluated about the effects of surface states on the corrosion or metal ion dissolution property of Alloy 690TT and the experimental works are needed for multi-application of shot peening and electropolishing treatment.

The aim of this work is to study on the reducing the dissolution of metal ions from Alloy 690 surface by surface modification in the simulated water chemistry of the primary system in PWRs. In this work, it was investigated the applicability of shot peening and electropolishing surface treatment on steam generator tube material and was evaluated the effect on corrosion release behavior by these surface treatments.

2. Experimental

The corrosion experiments were performed using Alloy 690TT, which was heat processed by two steps, mill annealed, and thermal treated.

The surface stress modification was applied by the shot peening (SP) method. SP was performed on the flat specimen using ceramic beads (0.125 ~ 0.250 mm size). Maximum air pressure for the SP instrument was 5 bars. The intensity and coverage during the SP process was measured using N-type Almen strips. Almen strips are flat metal strip and residual surface compressive stresses will make the strip bow upward in the middle when released. The height of this bowed arc is an index of the intensity of the SP.

The electropolishing (EP) process was applied by an ElectoMet® 4 (Buehler Co, IL). The electrolyte for electro-polishing was a mixture of 70% phosphoric acid (H_3PO_4), 15% sulfuric acid (H_2SO_4) and 15% methanol (CH_3OH). A recirculation loop with a Hastelloy autoclave system was used during the long time corrosion tests. The test environment simulated the primary water chemistry in PWRs. Dissolved oxygen (DO), dissolved hydrogen (DH), pH and conductivity were monitored at room temperature using sensors manufactured by Orbisphere and Mettler Toledo. The temperature and pressure were maintained at 330℃ and 150 bars during the corrosion test. The condition of the test solution was lithium (LiOH) 2 ppm and boron (H_3BO_4) 1,200 ppm, DH 35 cc/kg (STP) and less than 5 ppb DO. The flow rate of the loop system was 3.8 L/hour. Corrosion tests were conducted for 500 hours.

The corrosion release rate was evaluated by a gravimetric analysis method using a two-step alkaline permanganate-ammonium citrate (AP/AC) descaling process.

3. Results and Discussion

Surface residual stress can affect the metal ion release from the matrix to solution during the corrosion procedure. The arc deflection of N-type Almen strip defines the peening intensity. The shot peening intensity was measured as a value of 10.1N for an air pressure of 2 bar and a shot peening time of 30 sec. When the air pressure was down to 1 bar and 0.5 bar, the intensities decreased to 7.36N and 5.51N for a shot peening time of 60 sec. After these shot peening times, each value of intensity shows no more increase. Fig. 1 is a graph of the residual stress measured on the crystal face of Ni(111) and Ni(311) on the surface of specimens and microhardness. Both stress levels have a different value but show a similar pattern with air pressure during the shot peening. This result indicates that the specimen D for an air pressure of 2 bar shows a lower residual stress level than specimen B for an air pressure of 0.5 bar, which assumed to be less compressive residual stress. Microhardness was measured at a 20 μm depth from the shot peened surface. The hardness increases with the shot peening intensity, and specimen D shows the most hardening state.

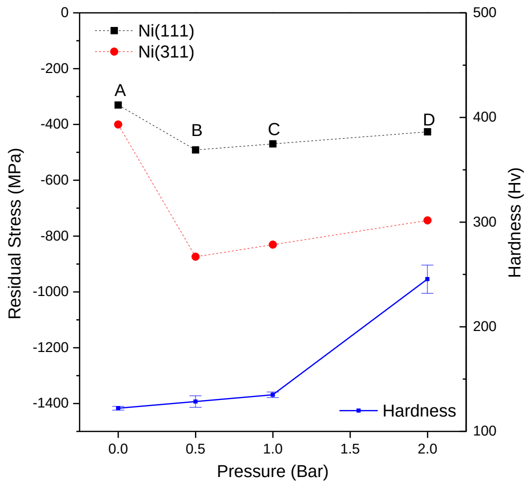

Fig. 1. Residual stress state and micro-hardness with SP air pressure

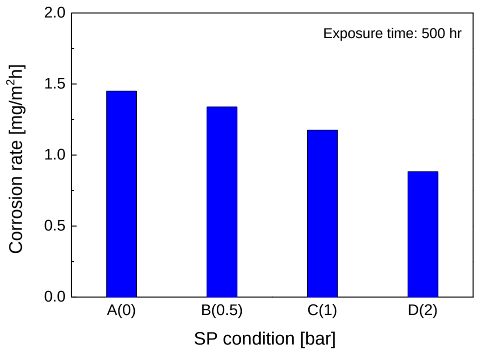

Fig. 2. Corrosion rate with SP air pressure.

After an exposure time of 500 hr at 330°C (150 bar), the corrosion rate was measured using a descale method and the results are shown in Fig. 2. The corrosion rate for test of different air pressure was measured as a value of 1.45 mg/m^2 hr for as-received specimen A. The corrosion rates of specimens with different shot peening treatment were shown to have values of 1.34, 1.18, and 0.88 mg/m^2 hr for B, C, and D specimens, respectively. The D specimen with a high shot peening intensity shows about a 40% decrease of corrosion rate than that of the as-received specimen A.

4. Conclusions

Compressive residual stress is induced by shot peening treatment but its value reveals some different trend between the shot peening intensity on the surface of Alloy 690 TT. A higher shot peening intensity causes a reduction in the corrosion rate and it is considered that the compressive residual stress beneath the surface layer suppresses the metal ion transfer in an alloy matrix.

Acknowledgements

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REFERENCES

[1] F. Carette, Impact of the surface state of steam generator tubes on the release of corrosion products in pressurized water reactors, Int'l Conf. on Water Chemistry of Nuclear Reactor Systems, Jeju, Korea, 2006.
[2] M. Clauzel, M. Guillodo, M. Foucault, Correlation between Ni base alloys surface conditioning and cation release mitigation in primary coolant, NPC, Quebec, 2010.
[3] L. Guinard, O. Kerrec, D. Noel, S. Gardy, F. Coulet, Influence of the initial surface conditions on the release of nickel alloys in the primary circuit of PWRs, EDF Report, 97NB00045, 1997.
[4] F. Huang, J. Q. Wang, E. H. Han, W. Ke, Short-time oxidation of alloy 690 in high-temperature and high-pressure steam and water, J. Mater. Sci. Tech., vol. 28, p. 562, 2012.
[5] J. J. Kai, C. H. Tsai, G. P. Yu, The IGSCC, sensitization, and microstructure study of Alloys 600 and 690, Nuclear Engineering and Design, vol. 144, p. 449, 1993.
[6] Z. Zhang, J. Wang, E. H. Han, W. Ke, Effects of surface state and applied stress on stress corrosion cracking of Alloy 690TT in lead-containing caustic solution, J. Mater. Sci. Tech., vol. 28, p. 785, 2012.
[7] P. Hernalsteen, PWSCC in the tube expansion zone – an overview, Nucl. Eng. Des., vol. 143, p. 131, 1993.
[8] V. N. Shah, D. B. Lowenstein, A. P. L. Turner, Assessment of primary water stress corrosion cracking of PWR steam generator tubes, Nucl. Eng. Des., vol. 134, p. 199, 1992.