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Corrosion behavior for Alloy 690 and Alloy 800 tubes in simulated primary water

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ABSTRACT

Corrosion behavior for Alloy 690 and Alloy 800 in simulated primary water is studied by open-circuit potential (OCP) measurement, electrochemical impedance spectroscopy (EIS) and potentiodynamic polarization. Rise of pressure and temperature lead to negative shift of corrosion potential for both Alloy 690 and Alloy 800. EIS results show that the effect of pressure on corrosion only exists in low-frequency region, while the effect of temperature presents at the entire frequency range. Alloy 690 shows a better corrosion resistance than Alloy 800 at present investigated conditions.

1. Introduction

Due to high stress corrosion cracking and corrosion resistance in high temperature pressurized water, Alloy 800 and Alloy 690 as the alternative materials for Alloy 600, have been widely used as stream generator heat transfer tubing materials in nuclear power plants (NPPs) [1–7]. There are no reports of stress corrosion cracking (SCC) failures in SG tubings made of Alloy 690 [3,5,6] exposed to pressurized water reactor (PWR) environments up to now, and no failure of Alloy 800 SG tubings in CANDU plants [6,7]. The operating time of Alloy 800 as SG tubing in service has been more than 40 years, and is 22 years longer than Alloy 690, since the first use of Alloy 690 and Alloy 800 began in 1989 and 1967 respectively [6,8]. The operating experience with CANDU fleet confirms Alloy 800 with only about 20% Cr concentration has superior performance in service [7]. However, for the laboratory studies, Le Canut et al. [9] reported Alloy 690 has lower corrosion rate than Alloy 800 in sulfate solution at 320 °C. Vaillant et al. [10] found Alloy 800 exhibited worse SCC resistance than Alloy 600 and Alloy 690 in 100 g/l NaOH + 10 g/l PbO solution at 350 °C. Alloy 690 is more resistant than Alloy 600, Alloy 800, and Type 304 stainless steel to SCC in oxygenated and deoxygenated, high-purity water, with and without crevices and chloride or lead contamination [11]. With the increasing demand of life extension for nuclear power plants (NPPs), the long-term resistance to cracking for Alloy 690 and Alloy 800 still have yet to be fully addressed. It is important to compare the corrosion behavior of Alloy 690 and Alloy 800 and clarify their corrosion mechanism in simulated high temperature pressurized water.

Generally, the high temperature water corrosion [12] and primary water stress corrosion cracking (PWSCC) [13] are basically electrochemical processes. Therefore, the possibility of predicting stress corrosion cracking (SCC) from electrochemical measurements has aroused considerable interest for nuclear industry [9]. Nevertheless, due to the manufacturing difficulties in high temperature high pressure reference electrode and the high performance material for sealing and insulation, many electrochemical works about the corrosion behavior for heat transfer materials, such as Alloy 690 and Alloy 800, were limited at room temperature with low pressure in the past [14–18]. There are few works about high temperature high pressure electrochemical experiments carried out in water loop system, especially the effect of pressure and temperature on corrosion behavior. Combining with in situ EIS measurement results and ex situ analysis of the oxide film, Bojinov et al. [19–21] have estimated kinetic and transport parameters of the oxidation process by quantitative comparison of the results with the Mixed-Conduction Model (MCM) for Alloy 690 and AISI 316L(NG) stainless steel. Whillock and Harvey [22] found that in the absence of ultrasound, the corrosion rate for 304L stainless steel in 2 M nitric acid with 2 g/L Cl^- was independent of pressure. Beccaria et al. [23] concluded that by increasing the hydrostatic pressure, the corrosion rate and the susceptibility to pitting of nickel increased in NaCl solution and decreased in sea water. Based on the results of stainless steel 304 [24] and Alloy 625 [25], it is clear that the activation energy is different at room temperature and high temperature. However, it is still not clear about the effects of pressure and temperature on corrosion.

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This paper is aimed to study the effects of pressure and temperature on the corrosion behavior for Alloy 690 and Alloy 800 in simulated primary water and to compare the performance of these two alloys in high temperature water.

2. Experimental

2.1. Materials

The commercial steam generator tubing materials, Alloy 690 and Alloy 800, were used. The tube size is ϕ 19.05 mm (OD) × 1.09 mm (thickness) for Alloy 690 and ϕ 15.88 mm (OD) × 1.13 (thickness) mm for Alloy 800 respectively. Chemical compositions of Alloy 690 and Alloy 800 are listed in Table 1.

The samples were cut from Alloy 690 and Alloy 800 tubes as shown in Fig. 1a. The arc angle was 72° for Alloy 690 samples, and 90° for Alloy 800 samples. Pure nickel wire was spot-welded to the inner side of the arc of the samples. Heat-shrinkable polytetrafluoroethylene (PTFE) tubes were used for shielding the nickel wire. Inner side and cross-section of the arc for the samples were carefully ground using 1000 grit SiC paper, while the outer side of the arc was ground and polished using 3.5 μm diamond pastes.

A FEI XL30 field emission environmental scanning electron microscopy (ESEM) equipped with an energy dispersive spectrometer (EDS) was used to examine microstructure and corrosion product of Alloy 690 and Alloy 800.

2.2. Autoclave with re-circulated water loop

The autoclave with re-circulated water loop used in present experiments was self-built and schematically shown in Fig. 1b. The autoclave lid was made of 316 stainless steel and the autoclave body was made of 321 stainless steel with a 3 mm thick lining of nickel with 99.6% purity welded to the inside of autoclave body. Tubes used in the loop were 316 stainless steel manufactured by SANDVIK. An external Ag/AgCl/KCl (0.1 M) electrode and a holder with 4 holes inside used to seal the wires for working electrodes and counter electrode were equipped at lid of the autoclave. All the electrodes were fabricated by Toshin Kogyo Co., Ltd., Japan.

The water chemistry parameters in the low-pressure water loop, such as dissolved oxygen (DO), pH and conductivity, were continuously monitored using sensors made by METTLER TOLEDO, and strictly controlled to simulate primary water chemistry in PWR. The automatic monitor and control were fulfilled by computer program written with LabVIEW 8.5. Detailed experiment parameters are listed in Table 2.

Table 1
Chemical composition for Alloy 690 and Alloy 800 tubes.

Material type	Element (Wt.%)												
	Ni	Cr	Fe	Mn	Ti	S	P	C	N	Si	Cu	Co	Al
Alloy 690	59.50	29.02	10.28	0.30	0.33	0.001	0.009	0.018	0.0234	0.31	0.010	0.015	0.16
Alloy 800	32.76	21.90	43.10	0.49	0.46	0.001	0.013	0.017	0.015	0.45	0.015	0.010	0.28

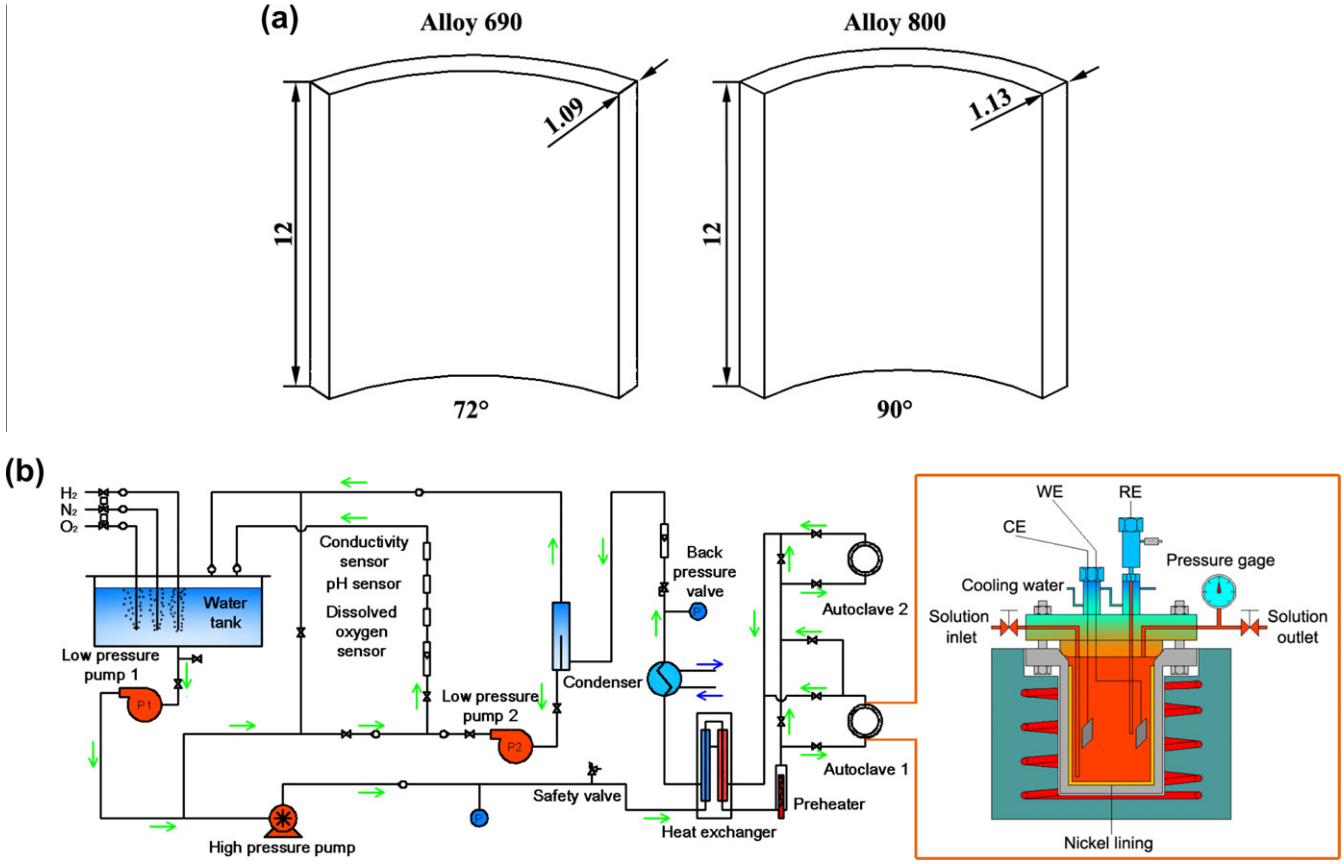

Fig. 1. Schematic diagrams of (a) high temperature high pressure electrochemical sample cut from alloy tubes and (b) high temperature high pressure water loop system.