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Effect of dissolved oxygen on PWSCC susceptibility of Alloy 600 in high temperature water

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Dissolved oxygen concentration in water significantly influences the corrosion behavior of metals. The corrosion rate of structural materials for nuclear power plant, such as carbon steels and turbine steels, increases as the dissolved oxygen concentration in water increases [1–3]. The SCC susceptibility of 304 or 316 stainless steel increases with increasing the oxygen content from 0.2 ppm to 10 and 100 ppm [4]. The dissolved oxygen concentration in nuclear power plants is controlled strictly because the increase of the dissolved oxygen concentration induces the increase of the corrosion rate and the related corrosion problems.

There are not enough studies about the effect of dissolved oxygen in water on the SCC susceptibility of Alloy 600 though it is considered that the dissolved oxygen concentration significantly affects the corrosion behavior. Page [5] and Berry [4] studied the effect of dissolved oxygen on the SCC susceptibility of Alloy 600. But they had no convincing correlation between the oxygen content and the susceptibility. The effect of dissolved oxygen concentration on stress corrosion cracking of Alloy 600 in high temperature water was investigated by constant elongation rate test (CERT) with hump type specimens in this study.

Slow strain rate tests (SSRTs) with the hump type specimens (Fig. 1) were carried out to investigate stress corrosion cracking susceptibility in various environments by a CERT machine and loop system at strain rate range of 1.25×10^{-7}/s–5×10^{-7}/s. Hump specimens were used to accelerate stress corrosion cracking by introducing complex stress distribution around the bent area. Chemical composition and mechanical properties of specimens are shown in Tables I and II. Tests were conducted at 360 °C in deaerated (dissolved oxygen <10 ppb) and in air saturated water (dissolved oxygen $= 7.8$ ppm). Nitrogen gas injection was carried out continuously into the loop to control the dissolved oxygen concentration of the testing environments.

The occurrence of SCC on the fracture surfaces was examined by the SEM (scanning electronic microscopy) observation after the tests. SCC susceptibility was evaluated by comparing the load-deformation, the maximum elongations and the maximum loads in the testing environments.

Load-deformation curves of Alloy 600 for the SCC tests at 360 °C at a strain rate of 2.5×10^{-7}/s in aerated and in deaerated water are shown in Fig. 2. Load increases linearly with the increase of deformation in the elastic range of the load-deformation curve. Beyond the elastic range, the slope of load to deformation decreases until the load arrives at the maximum value in the aerated environment. After arriving at the maximum loads, the specimens fail immediately. In the deaerated environment, the load maintain near constant values after the elastic range. The maximum deformation is

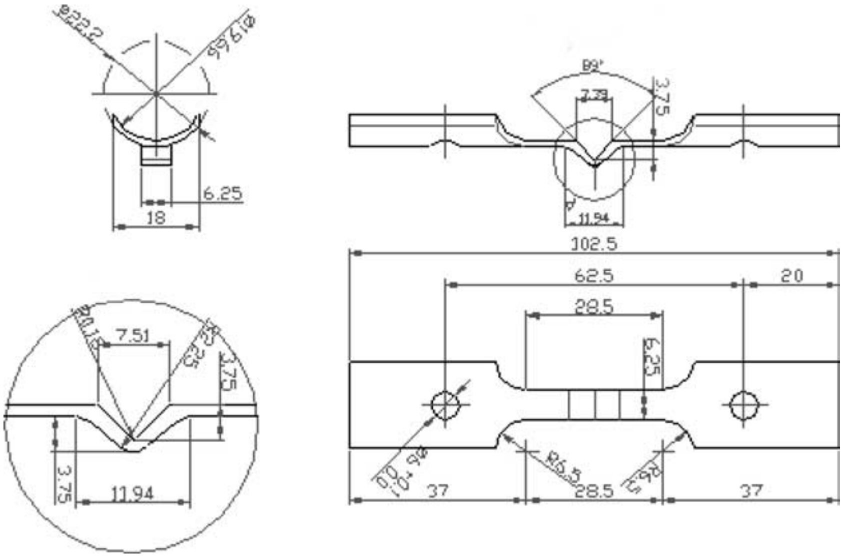

Figure 1 Geometry of hump specimen for SCC tests.

TABLE I Chemical composition of Alloy 600 specimen

Alloy 600	Ni	Cr	Fe	Mn	C	Cu	Si	S
wt%	75.1	15.4	8	0.3	0.01	0.2	1	0.001

TABLE II Mechanical properties of Alloy 600

Material (ASTM B-167)	Heat no.	UTS (Kg/ mm^2)	Y. S. (kg/ mm^2)	Elong. (%)	H. treat.	Grain size (ASTM no.)
Alloy 600	906007	66.20	29.58	46.00	960 °C, 10 min	6.89

3.7 mm (elongation ratio: 12.3%) in an aerated environment, and 2.5 mm (elongation ratio: 5.5%) in a deaerated environment for the tests shown in a) of Fig. 2. The maximum deformation and the maximum load in the deaerated environment showed a significant decrease compared with those in the aerated environment. These SCC behaviors of Alloy 600 in the two extreme environments were confirmed by a repetitive test as shown in b) of Fig. 2.

Fracture morphologies of specimens for the two environments (in aerated and deaerated water at 360 °C) are shown in Figs 3 and 4. The morphologies of the fracture surface in the two extreme environments have significant differences. The tendency of intergranular stress corrosion cracking in the deaerated environment is more obvious than in the aerated environment. As shown in Fig. 3, in the deaerated environment, intergranular cracks initiate at the surface and propagate into the inner area continually to final failure ligaments. But in the aerated environment, there is no intergranular stress corrosion cracking except in the limited region of pseudo-SCC as shown in a) of Fig. 4 in the fracture surface.

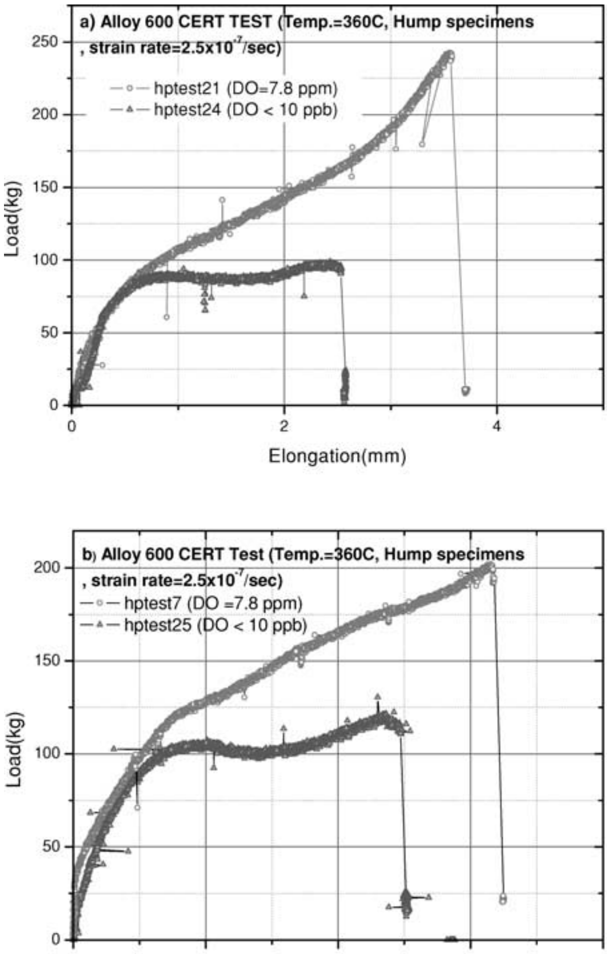

Figure 2 Load-displacement curve of Alloy 600 hump specimens tested in aerated and deaerated water at 360 °C.

Dissolved oxygen in the corrosion environment significantly influences the stress corrosion cracking behavior of Alloy 600 based on the test results of this study. Stress corrosion susceptibility of Alloy 600 in aerated water significantly decreased compared with the susceptibility of the alloy in deaerated water.

Corrosion of a metal is accomplished by the combination of oxidation of the metal and the reduction of hydrogen ions or oxygen molecules. In the case of the high concentration of dissolved oxygen in water, the reduction reaction in the corrosion process is mainly accomplished by the oxygen reduction as in this reaction.

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$$

If the concentration of dissolved oxygen in this reduction reaction increases, the current for this reduction reaction increases. The corrosion potential is decided at the point where the current produced by oxidation is completely consumed by reduction. So the increase of reduction current increases the oxidation current at the corrosion potential if no passive film is formed on the metal. When passive film is formed by the oxidation of the corroding metal, the current density in the passive range drastically decreases during the corrosion process.

It is considered that the decrease of stress corrosion cracking susceptibility in aerated water has a strong relation with the protectiveness of the surface passive film formed in that environment. Stress corrosion cracks usually propagate by repeating the fracture of the passive film and anodic metal dissolution. The SCC resistance increases in aerated water because the amount of metal anodic dissolution drastically decreases due to the protective oxide layer at the crack tip in the aerated water environment. On the other hand, in the deaerated water environment, the SCC susceptibility is high because the anodic dissolution at the crack tips is active.

In conclusion, dissolved oxygen concentration significantly influences the SCC susceptibility of Alloy 600 in pure water at 360 °C. The SCC susceptibility of Alloy 600 decreased remarkably in an aerated water environment compared with a deaerated water environment. It is considered that the protective oxide layer in the higher dissolved oxygen water decreases the amount of anodic metal dissolution at the crack tips and so decreases the SCC susceptibility of Alloy 600 in that environment.

Further work will involve characterizing the surface oxide microstructures of Alloy 600 in two extreme environments and correlating the oxide structures with the degree of the protectiveness to PWSCC in high temperature water.

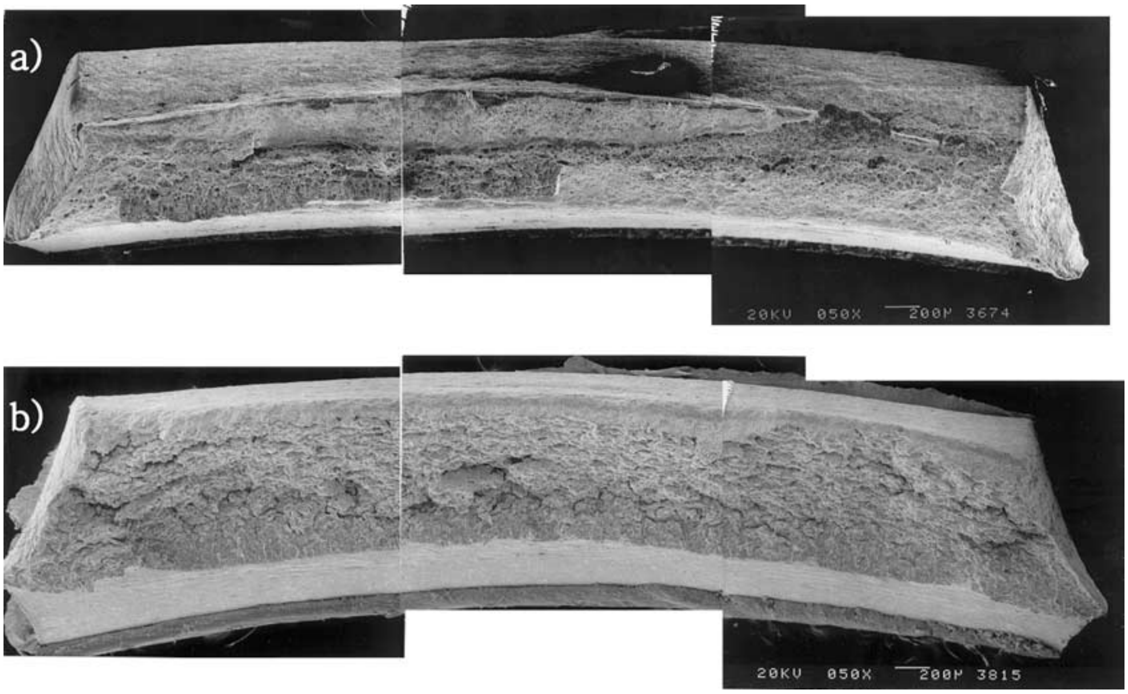

Figure 3 Fracture morphologies of hump specimens tested in: (a) aerated water (hptest21, dissolved oxygen: 7.8 ppm) and (b) deaerated water (hptest24, dissolved oxygen < 10 ppb) at 360 °C.

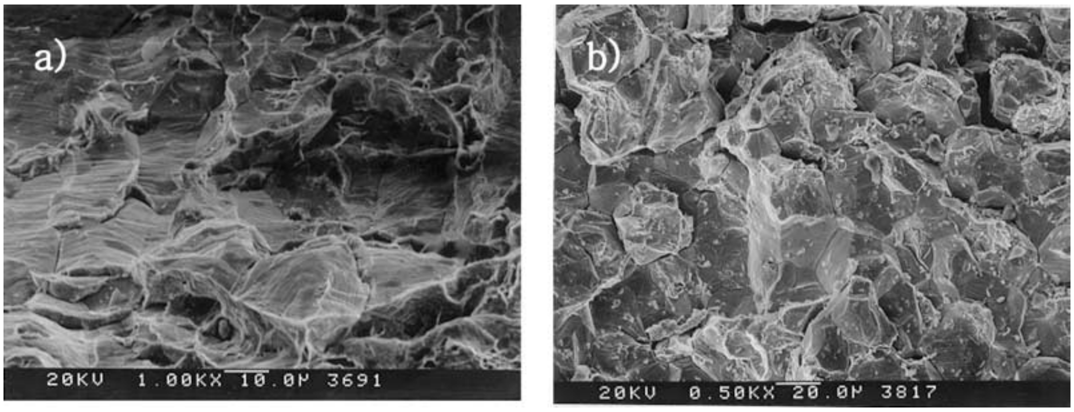

Figure 4 Magnified view of fracture morphologies tested in: (a) aerated water (hptest21, dissolved oxygen: 7.8 ppm) and (b) deaerated water (hptest24, dissolved oxygen < 10 ppb) at 360 °C.

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