

Electrochemical Fracture Model of the Stress Corrosion Cracking of Turbine Steel in High Temperature Water

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1. Introduction

One of the problems in using ETA in turbines is the formation of organic acids, such as acetic acid, formic acid, and galactic acid, due to the thermal decomposition [1]. In the present work, the impact of acetic acid on the susceptibility of 3.5NiCrMoV (ASTM A470/471) turbine steel to stress corrosion cracking (SCC) was studied as a function of acetic acid concentration. The SCC behavior of turbine steel in solutions of various acetic acid concentrations was analyzed in terms of the CEFM (Coupled Environment Fracture Model) [2] and the observed, enhanced susceptibility of SCC due to acidification of the early condensate due to acetic acid is readily accounted for by the electrochemical fracture model.

2. Experimental Method

The CERTs (Constant Extension Rate Tests) were conducted to understand the effects of acetic acid concentration on the SCC susceptibility of the turbine steels. Experiments were conducted in deaerated water containing various acetic acid concentrations (1.83×10^{-5} M - 2.19×10^{-2} M; pH (22 ± 2°C) = 4.95 - 3.21) at 150°C at a strain rate of 1×10^{-7} s⁻¹.

3. Experiment Results

Stress-strain curves for ASTM A470/471 (3.5NiCrMoV) turbine disk/rotor steels measured in CERTs in water containing various concentrations of acetic acid [1.83×10^{-5} M - 2.19×10^{-2} M; pH (22 ± 2°C) = 4.95 - 3.21] at 150°C at a strain rate of 1×10^{-7} s⁻¹ are shown in Table 1 and Figure 1. In Figure 2, the RA of the specimens decreases from around 40% to 8% as the pH decreases from 4.95 to 3.50. For pH = 3.21, the RA of the specimens increases again to 46%. The decrease in RA indicates an increase in the tendency toward brittle fracture due to SCC. Up to pH = 3.50, the SCC susceptibility increases as the pH decreases. For pH = 3.21, very severe general corrosion was observed. The major fracture mechanism in the solution pH = 3.21 is ductile fracture with uniform corrosion on the surface of

the specimens, possibly reflecting crack blunting due to dissolution. 3.5NiCrMoV Steel, 1×10^{-7} /sec, in deaerated water(acetic acid added)

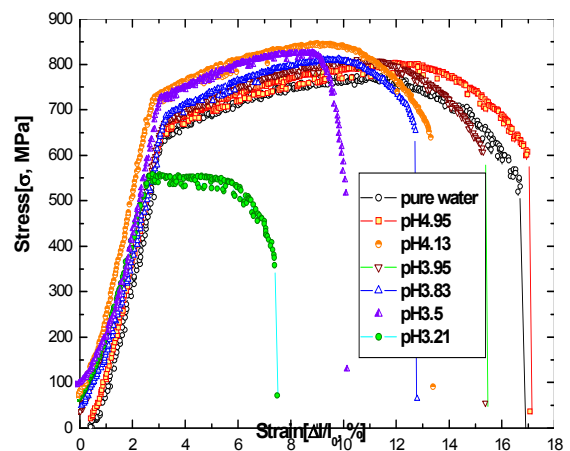


Fig. 1 Strain-stress curves of the 3.5NiCrMoV turbine steels tested in water of various acetic acid concentration at 150 °C.

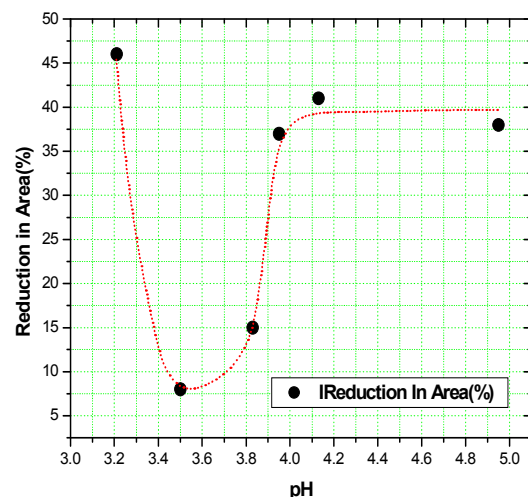


Fig. 2 Reduction in Area (%) of specimens tested in various acetic acid concentrations (pH 3.21~4.95)

4. Discussion

The variation of acetic acid concentration affects the CGR (Crack Growth Rate) of turbine steels by: 1)

Changing the solution pH, which, in turn, affects the exchange current densities and the equilibrium potentials of the redox reactions that occur on the external surface (O_2 , H_2O , and H^+ reduction) and which consume the positive current exiting the crack mouth; 2) Changing conductivity of the solution and hence the “throwing power” of the current from the crack mouth, and; 3) Changing the ECP and the potentials at the crack tip and crack mouth.

The variations of various solution and crack properties, such as the pH, conductivity, ECP, and the potentials at the crack tip and crack mouth, as a function of the acetic acid concentration at room temperature and at $150^\circ C$, were calculated using an electrochemical fracture model of the CEFM.

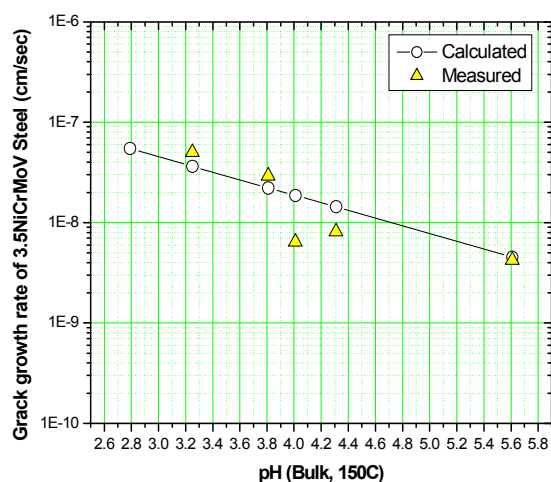


Fig. 3 The measured and calculated CGR as a function of the bulk solution pH at $150^\circ C$

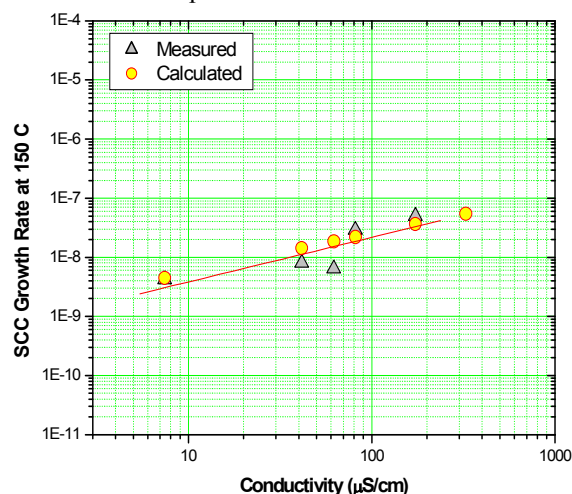


Fig. 4 The CGR at $150^\circ C$ as a function of the conductivity at $150^\circ C$

The calculated and measured CGR are related with the pH_{bulk} at $150^\circ C$ in Figure 3. The measured CGR is

estimated by assuming that the crack is initiated at the beginning of the tests and by measuring the crack length on the fracture surface. Both CGRs seem to increase logarithmically with decreasing pH_{bulk} at $150^\circ C$, as shown in Figure 12. However, the effect of pH_{bulk} on the CGR is not simple, because several factors (pH, conductivity and ECP) are strongly coupled during crack growth. To confirm the effect of pH on the CGR, it is imperative to understand the effect of the pH on the thermodynamics and kinetics of the iron electrode.

The measured and calculated crack growth rate, as a function of the conductivity of the external environment, is shown in Figure 4. The relationship of crack growth rate (measured and calculated) and the conductivity shows logarithmic linearity. It is clear that the linearity between the CGR and the conductivity reported in this study illustrates the importance of the solution conductivity in determining the SCC susceptibility of turbine steels. This finding agrees with many experimental observations that have led some authors to postulate that conductivity may be the dominant parameter in determining the SCC susceptibility of various steels to fracture in low pressure steam turbine PTZ (Phase Transition Zone) environments.

5. Summary and Conclusions

Acetic acid, in the external corrosion environment, significantly influences the SCC susceptibility of 3.5NiCrMoV steels. The impact of solution properties, such as pH, conductivity, and ECP are interactive and the conductivity of the solution is considered to be an important factor influencing the severity of SCC damage.

When calibrated on a single crack growth rate/ECP/conductivity/stress intensity/temperature datum, the Coupled Environment Fracture Model (CEFM) provides a good account of stress corrosion cracking of ASTM A470/471 turbine disk/rotor steels in simulated low pressure steam turbine PTZ environments containing acetic acid impurity.

REFERENCES

- [1] M. De Wispelaere, “Early condensate in a fossil power plant using organic treatment”, 14th International Conference on the Properties of Water and Steam, Kyoto, Japan, (2004) 602.
- [2] C. Liu and D. D. Macdonald, *J. Press. Vess. Tech.*, 119 (1997), 393.