PWSCC in Alloy 600 and IG Crack Growth Rates in PWR environments

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1. Introduction

Austenitic nickel-based Alloy 600 has been used as structural materials in nuclear power plants due to its good mechanical properties and high corrosion resistance. However, PWSCC(Primary Water Stress Corrosion Cracking) occurs in the primary-circuit structural materials fabricated from Alloy 600, such as reactor vessel head nozzles including CRDM(Control Rod Drive Mechanism) and in-core instrument nozzles [1,2]. Depending on test conditions, microstructure of components and so on, crack growth rate in stress corrosion cracking is significantly different. Many researches on stress corrosion cracking in primary water reactor environments have been carried out to demonstrate effects of various factors on crack growth rate [3,4,5].

It is the purpose of this study to investigate effects of stress intensity factor (K) value on crack growth rate of a wrought alloy 600 in primary water reactor environments.

2. Methods and Results

2.1 Materials and Test specimens

A 0.5 inch thick CT(Compact Tension) specimen with 10% side grooves was machined from the TL orientation of the wrought alloy 600 plate. So the crack was propagated parallel to the rolling directing.

2.2. Pre-crack

Prior to the test in PWR environments, Cyclic loading at room temperature in air induced a fatigue pre-crack of about 2mm length. K_{max} values of the pre-cracking were adjusted to 0.8 times of the K_{max} value for the SCC growth test in a PWR water chemistry.

2.3 Water Chemistries

SCC growth rate tests were carried out at 340℃, 160bar in an autoclave with a recirculation loop. During the test, the water flow rate was 9 L/h and the water in an autoclave was refreshed with 2.38 cycle/h. ECP(Electrochemical Potential) measured using a Ag/AgCl reference electrode, Dissolved Oxygen, Dissolved Hydrogen, conductivity and pH were detected to monitor the water chemistry condition.

2.4 Micro-structure

An Alloy 600 structure assessed from the carbide precipitation is a good indicator of the material PWSCC susceptibility[6,7]. So, Bromine methanol etching was carried out to observe the structure of the specimen. Fig. 1 shows Cr-rich carbides precipitates at both inter and intra grain boundaries. It is believed that the precipitate phases are Cr-rich M_7C_3 and $M_{23}C_6$ carbides and Ti(C,N) carbon nitrides. As shown in Fig. 1, the continuous carbide film at the grain boundaries results in the significant decrease in the SCC growth rate.

2.5 SCC growth rate test

Figure 2 shows crack growth rates in the wrought alloy 600. Here, S and S' are crack growth rates and the subscripts are the corresponding test steps in Table 1. Referring to the decrease in frequency from S1 to S2 of Table 1 and the corresponding decrease in crack growth rate of Fig. 2, the crack growth rate decreases linearly with decreasing frequency. A linear line S1S'4 is therefore a line that is expected when only a fatigue crack is considered. During testing, the crack growth rate increases drastically from S2 to S'3 or S'4, instead of following the linear line from S2 to S'4. This implies that an additional phenomenon is superimposed from S3 on the fatigue cracking.

SEM images of the fracture surface after testing are shown in Fig. 4. The fracture surface is divided into four parts: initially fatigue-cracked region, TGSCC region, IGSCC region and finally fatigue-cracked region. Primary water stress corrosion cracking, which shows a mostly intergranular fracture mode, is observed in an IGSCC region. Some transgranular fracture is also observed in the IGSCC region, the path of which seems to be twin boundaries. It is suggested also in this study that primary water stress corrosion cracking in the present alloy 600 proceeds through the repetition of the formation of oxide films at stress-concentrated grain or twin boundaries and their subsequent rupture [10]. Unlike the expectation for test loading conditions of Table 1, the change in fracture mode from transgranular to intergranular seems not to occur steadily through the steps 1~4 but abruptly at the step 5. This is because, referring to Fig. 4, the fracture mode in a TGSCC region is totally transgranular.

That is, within the present experimental condition, the crack growth rate decreased with decreasing K value. The crack growth rate curve for Alloy 600 [9] from the material reliability program (MRP) are shown in Fig. 3 together with the present data obtained at 340℃. The present experimental data is below the MRP curve. Such lower crack growth rates are probably due to the continuous carbide films at the grain boundaries which show a high resistance against primary water stress corrosion cracking.

3. Conclusion

Changes in crack growth rate with K value in primary water environments have been investigated in an alloy 600. Primary water stress corrosion cracking was observed after testing and the fracture mode was intergranular. The crack growth rate decreased with decreasing K value and the growth rate was lower than that reported in MRP-55 for Alloy 600. This is probably due to continuous carbide films at grain boundaries.

REFERENCES

[1] R.S. Pathania and A.R. Mcllree, EPRI TR-103345 (2000).
[2] E.S. Hunt and D.J. Gross, EPRI TR-103696 (1994).
[3] P.M. Scott, Corrosion 56, 771 (2000).
[4] G.A. White, J. Hickling and L.K. Mathews, 11th International Symposium on Environmental Degradation of Materials in Nuclear Power System, 166-178 (2003).
[5] N.H. Heo, Y.C. Jung, J.K. Lee and K.T. Kim, Scripta Mater, 59, 1200 (2008).
[6] G.S Was, Corrosion 46, 319 (1990).
[7] R.B. Rebak, Z.Zia, and Z.S. Smialowska, Corrosion 49, 867 (1993).
[8] J. Hicking, A. Mcllree, R. Pathania, EPRI TR-1006695 (2002).
[9] K. Ahluwalia, EPRI TR-1015288 (2007).
[10] F.P ford and P. L. Andresen, 3th International Symposium on Environmental Degradation of Materials in Nuclear Power System, 789 (1987).

Table 2. Test Condition

STEP	K_{max} (MPa√m)	Load Ratio, R	Dissolved Hydrogen, cc/kg H_2O	Frequency
S1	30	0.7	30	0.1Hz (sine)
S2	30	0.7	30	0.01 Hz (sine)
S3	30	0.7	30	0.001 Hz (triangle)
S4	30	0.7	30	0.001 Hz + holding for 9 ks at K_{max} (Trapezoidal)
S5	30	-	30	Constant K
S6	20	0.7	30	0.001 Hz + holding for 9 ks at K_{max} (Trapezoidal)
S7	20	-	30	Constant K
S8	20	-	8	Constant K

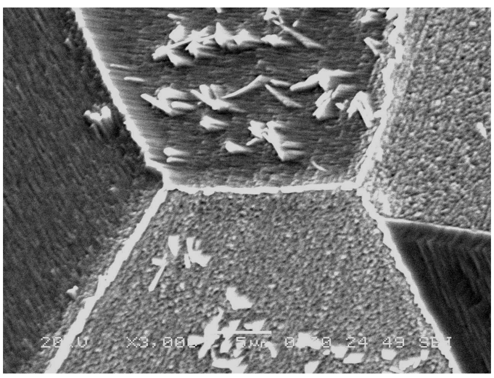

Fig. 1. The microstructure of the alloy 600 etched in a Bromine Methanol solution. Magnification: x3,000.

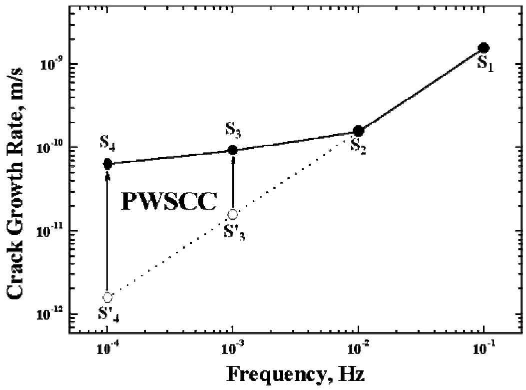

Fig. 2. A relationship between frequency and crack growth rate

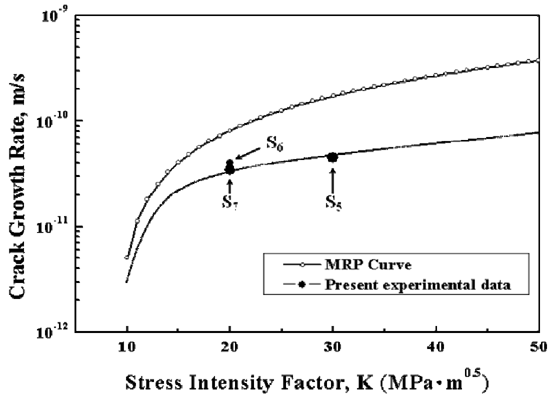

Fig. 3. A Comparison between the present SCC growth rates and a MRP curve for Alloy 600 in PWR

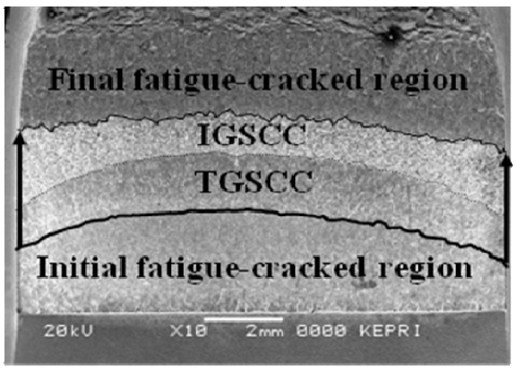

Fig. 4. A Comparison between the present SCC growth rates and a MRP curve for Alloy 600 in PWR