Comparison of Equations for Predicting Primary Water Stress Corrosion Crack Growth Rates in a Surge Nozzle Weld on the Hot Leg Side

Kyung-Hwan Na*, Eunsub Yun, Young Sheop Park
Nuclear Engineering & Technology Institute, Korea Hydro & Nuclear Power Co. Ltd.,
25-1 Jang-Dong, Yuseong-Gu, Daejeon, KOREA, 305-343
**Corresponding author: cylomon@khnp.co.kr*

1. Introduction

Nickel-based austenitic alloys such as Alloy 600 and the weld metals Alloy 82, and 182 have been employed extensively in nuclear power plants (NPPs) in Korea. During the construction of NPPs, it was widely believed that these alloys have high corrosion resistance as well as good mechanical properties. However, since the 2000s, the occurrence of primary water stress corrosion cracking (PWSCC) has been reported in conjunction with these alloys in oversea NPPs [1], and this has received international attention due to its potential effect on the structural integrity of piping in reactor coolant system.

Under these circumstances, PWSCC growth rate studies of Alloy 600/82/182 have become important issues, and many studies have been carried out as a result. The Electric Power Research Institute (EPRI) in the United States proposed two crack growth rate (CGR) equations for PWSCC in its MRP-21 [2], and MRP-115 [3] reports. On the other hand, the Nuclear Regulatory Commission (NRC) recommended one equation for this purpose [4].

In the present work, one instance of the initiation of an imaginary crack was assumed to exist at the inner surface of a surge nozzle weld on the hot leg side first. Subsequently, the CGRs were estimated for this initiated crack according to the MRP-21, MRP-115, and NRC equations. Finally, a comparison of the equations was made through their CGR results mainly in terms of their degree of conservatisms.

2. Methods and Results

In this section, the PWSCC CGR equations used to estimate the crack lengths are described first. Their results are then given for comparison. Fig. 1 shows the CGR curves for the MRP-21, MRP-115, and NRC equations.

2.1 Crack Growth Rate (CGR) Equations

The aforementioned three types of CGR equations are given below.

MRP-21 CGR (m/s) = $1.4 \times 10^{-11}(K-9)^{1.16}$ (1)
MPR-115 CGR (m/s) = $1.5 \times 10^{-12}(K)^{1.6}$ (2)
NRC CGR (m/s) = $2.1 \times 10^{-11}(K-9)^{1.16}$ (3)

where, K is the stress intensity factor (MPa√ m)

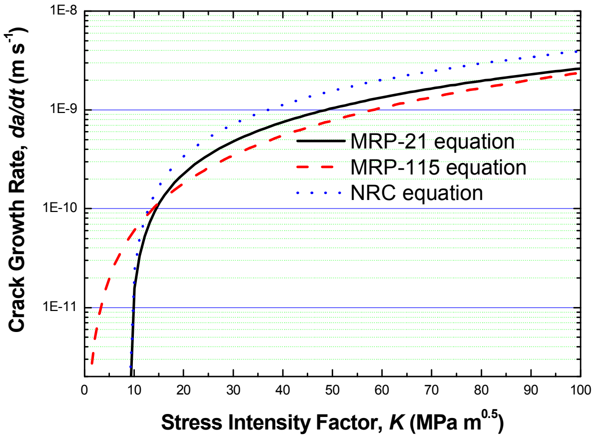

Fig. 1. Plots of crack growth rate against stress intensity factor for the MRP-21, MRP-115, and NRC equations.

It is worthwhile to note that the MRP-115 equation has no threshold value of the stress intensity factor for crack growth compared to the MRP-21 and NRC equations. This implies that for a given stress intensity factor value lower than 9 MPa√ m, a stress corrosion crack can grow only according to the MRP-115 equation. Among the three equations, the MRP-115 equation was suggested most recently based on extensive experimental results.

2.2 Geometry of the Surge Nozzle and Calculation of the Total Applied Stress

Fig. 2 presents a schematic diagram of the surge nozzle on the hot leg side taken into consideration in the present work.

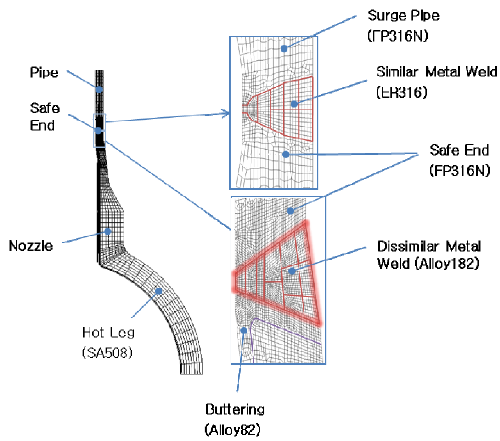

Fig. 2. Schematic diagram of the surge nozzle on the hot leg side.

The total stress applied to the nozzle weld was calculated using finite element analysis (FEA) to estimate the amount of PWSCC crack growth length in consideration of the residual stress caused by the welding processes. The resulting total stress curve is given in Fig. 3. The stress curve suggested by ASME is also illustrated in Fig. 3 for comparison. These stress curves were used to analyze the three CGR equations through the estimation of the crack growth lengths.

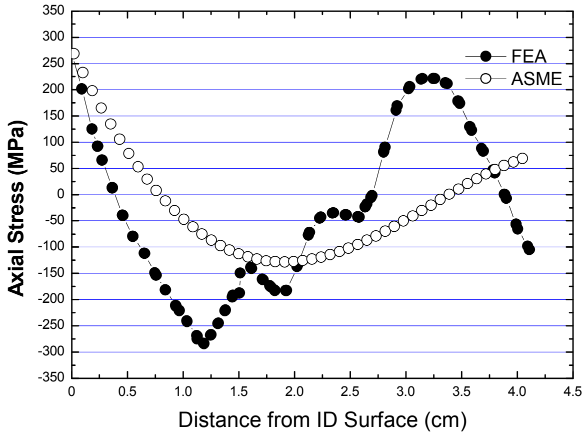

Fig. 3. Total applied stress curves calculated by FEA and suggested by ASME.

2.3 Calculation of Crack Growth Lengths

The crack growth lengths were calculated using the three CGR equations. Two types of stress curves were employed for the calculation as mentioned above. Some were estimated via the stress curve calculated by FEA (Fig. 4), and others were determined using the stress curve given by ASME (Fig. 5).

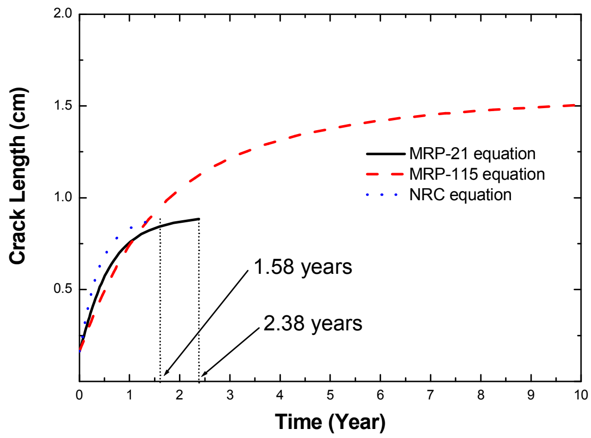

Fig. 4. Change in crack growth length with time based on the total stress calculated by FEA.

In Fig. 4, while the crack grew up to 21.40% (0.88cm) of the weld thickness within 2.38 and 1.58 years and stopped growing any further according to the MRP-21 and NRC equations, respectively, it was found that it grew up to 38.93% (1.60cm) of the weld thickness within 57.91 years and still kept growing at a very slow rate in the case of the MRP-115 equation.

In Fig. 5, the crack penetrated through the nozzle weld within 10.58 years according to the MRP-115 equation. On the other hand, it was revealed that it grew up to 47.44% (1.95cm) of the weld thickness within 12.58 and 8.38 years and stopped growing any further according to the MRP-21 and NRC equations, respectively.

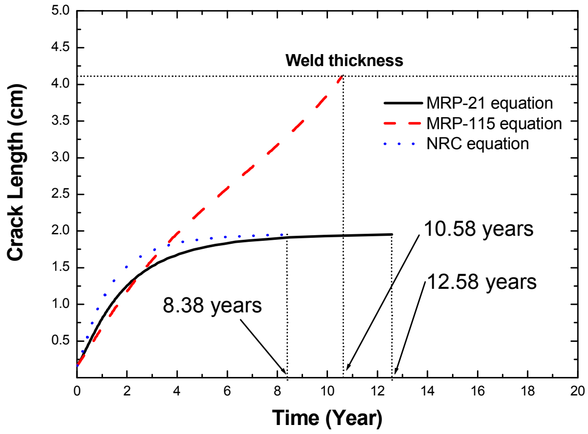

Fig. 5. Change in crack growth length with time based on the ASME stress curve.

3. Conclusions

Three types of equations for predicting PWSCC crack growth rates were evaluated in a surge nozzle weld on the hot leg side based on the total stress curves calculated by FEA and given by ASME. First, the crack growth length estimations based on the total stress given by ASME produced more conservative results than those estimations based on the total stress calculated by FEA. Second, in both stress curves, it was revealed that the MRP-115 equation gave the most conservative results compared to the other two equations for the surge nozzle weld under consideration in this study. It was suggested that this conservatism is mainly due to the absence of a threshold value for crack growth in the MRP-115 equation.

REFERENCES

[1] USNRC, Regulatory Approach for Primary Water Stress Corrosion Cracking of Dissimilar Metal Butt Welds in Pressurized Water Reactor Primary Coolant System Piping, Regulatory Issue Summary 2008-25, October 2008.

[2] EPRI, Crack Growth of Alloy 182 Weld Metal in PWR Environments(MRP-21), 1000037, June 2000.

[3] EPRI, Crack Growth Rates for Evaluating Primary Water Stress Corrosion Cracking (PWSCC) of Alloy 82, 182, and 132 Welds (MRP115), 1006696, November 2004

[4] USNRC, Safety Evaluation by the Office of Nuclear Reactor Regulation WCAP-15615, Integrity Evaluation for Future Operation Virgil C. Summer Nuclear Plant : Reactor Vessel Nozzle to Pipe Weld, Docket No. 50-395, February 2001.