# Crack Growth Rate Test for Evaluating Stress Corrosion Cracking of Alloy 600

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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, SCC(Stress Corrosion Cracking) occurs in the primary circuit structural materials fabricated from alloy 600 materials, such as reactor vessel head nozzles including CRDM(Control Rod Drive Mechanism) nozzle and In-core instrument nozzle.

SCC of alloy 600 has been reported in many plants in the world [1,2]. If CGRs(Crack Growth Rates) in SCC were known thoroughly, crack propagations could be predicted for evaluating the integrity. Because the CGRs are significantly different in test conditions and microstructure of components, many researches on SCC have been carried out to demonstrate effects of various factors [3,4]. The CGR curves require high quality data precisely to evaluate the integrity of the components.

This presentation describes micro-structural characteristics and the development in CGRs curve of wrought alloy 600 in PWR environments. The effect of K(Stress Intensity Factor) value on CGR is investigated.

## 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[5,6]. 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.

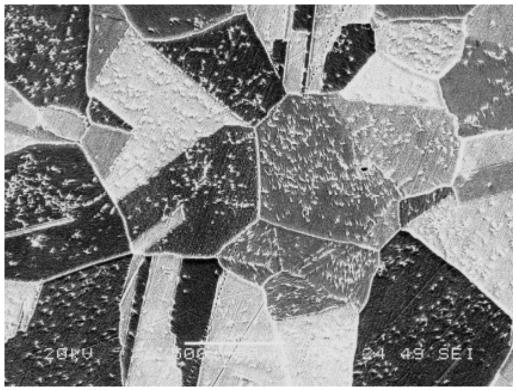

Fig. 1. The microstructure of the alloy 600 etched in a Bromine Methanol solution. Magnification: x500.

*2.4 SCC growth rate test*

The CGR test of alloy 600 specimen was performed at 340℃ and 160bar in simulated PWR environments. The CT specimen was loaded according to the guideline in Table1. Here, the steps 1~4 corresponds to the fatigue cracking. It is also supposed that, the transition will gradually occur from trans-granular cracking to inter-granular through the steps 1~4, although the step for the exact transition is not clear. It is assumed that the fracture modes from the step 5 are intergranular.

Table1. The loading condition guideline.

| STEP | Kmax (MPa√m) | Load Ratio, R | Frequency |
|---|---|---|---|
| 1 | 30 | 0.7 | 0.1Hz sine |
| 2 | 30 | 0.7 | 0.01 Hz sine |
| 3 | 30 | 0.7 | 0.001 Hz triangle |
| 4 | 30 | 0.7 | 0.001 Hz + 9 ks hold (Trapezoidal) |
| **5** | **30** | **Constant Load** | **Constant** |
| 6 | 20 | 0.7 | 0.001 Hz + 9 ks hold (Trapezoidal) |
| 7 | **20** | **Constant Load** | **Constant Load** |

During the test, the crack length resolution of the reverse DCPD(Direct Current Potential Drop) method was 10 ㎛. Fig. 2 shows a curve for crack length vs. time. Average CGRs were obtained after each step, respectively. It is shown in Fig. 2 that the crack growth rate is considerably influenced by the K value. The step 5 corresponds to 2.931 $\times 10^{-11}$ m/sec and the step 7 to 1.810 $\times 10^{-11}$ m/sec. Therefore, the growth rate in the step 7 became lowered approximately by 23% of that in the step 5.

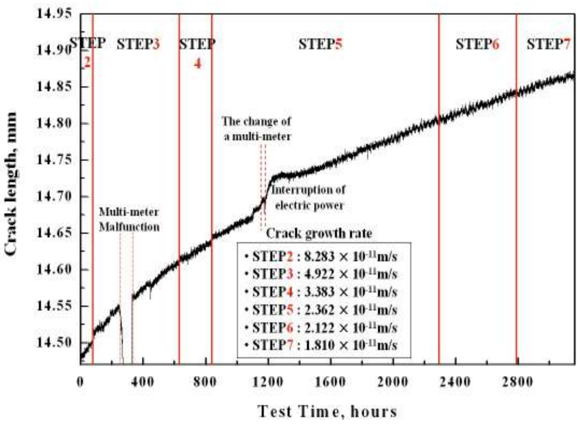


Fig. 2. Crack growth rate vs. test time for alloy 600.

Lots of CGR data for Alloy 600 [7] at 325℃ are shown Fig. 3 with the MRP curve suggested in ref [7] and the present data (red square) obtained at 340℃. The present data points which are obtained under a constant load are below MRP curve. Such lower crack growth rates are probably due to the continuous carbide film at the grain boundaries which shows the high resistance against the SCC propagation.

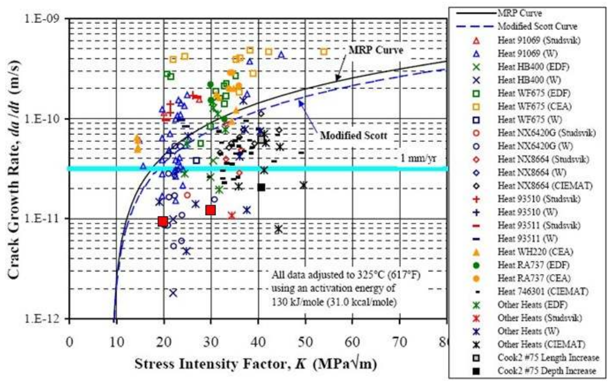


Fig. 3. The comparison of the SCC crack growth rate with the reference data [7] for alloy 600 in PWR.

### 3. Conclusions

Changes in CGR of alloy 600 with loading conditions in a PWR environment were investigated in this study. The main conclusions are as follows:

1. Pilot test for Alloy 600 SCC CGRs was successful. It was possible to monitor CGRs sensitively in real-time using reverse DCPD method and to control water chemistry condition and K.
2. The CGR was affected by the K value. The CGR under 30 MPa√m was 23% higher than that under 20 MPa√m
3. The CGR in this study was lower than that reported in MRP-55 for alloy 600. This is probably due to the continuous carbide film at the grain boundaries.

Some works are still in progress to assess effects of dissolved hydrogen concentration on CGR, and the CGR of alloy 182 will be also investigated.

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