Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 24-25, 2013

Initiation and Propagation of PWSCC of Alloy 600/690 in PWRs

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1. Introduction

Primary water stress corrosion cracking(PWSCC) of alloy 600 in a PWR has been reported in the control rod drive mechanism (CRDM)[1], In original PWRs, the SCC was not considered appropriately. Beginning in the mid seventies the world's PWR plants suffered from a sequence of SCC events mostly confined to S/G tubes, initially ODSCC then PWSCC. In thick wall alloy 600 materials, PWSCC was first reported in the Bugey 3 vessel head penetration in September 1991. The first report of a PWSCC in a SG drain nozzle was at the Shearon Harris plant in 1988. Two cases of boric acid precipitation were reported on the bottom head surface in two units of a SG in Korea.[2] Cracking was found only in the cold leg drain nozzles made of Alloy 600. On the other hand, the hot leg side nozzles are corrosion resistant Alloy 690 from the beginning of operation, and no crack indications have been observed yet.

The objective of the present work is to review the terminology of PWSCC initiation and propagation of alloy 600 and to compare crack initiation time of alloy 600 and 690 from a plant experience.

2. PWSCC Initiation and Propagation of Alloy 600

PWSCC initiation is related with multiple material parameters, e.g. heat treatment, yield strength, carbon content, carbide distribution, grain boundary composition and grain boundary precipitates, etc. And surface structure caused by grinding/polishing is also key factor to control the initiation time. Plant service exposure to primary water condition produces localized corrosion and oxidation in the heavily deformed surface structure. Then the localized area evolves to a setting point of a crack. Fig. 1 shows an example of the near surface microstructure, of which area is initial stage of a crack.[3]

Because the SCC is a thermally activated process, temperature behaves as another key role in crack initiation. The thermal effect can be expressed by activation energy, and the value of 185 KJ/mol to 210 KJ/mole was used for crack the initiation of Alloy 600 with reasonable consensus from some studies. [4,5] An apparent activation energy for Alloy182 crack initiation around 230 kJ/mol was estimated by L. Fournier, et al. [4]

Complexities generally concur that the term crack initiation is ambiguous, even within a given narrow audience like plant engineers, non-destructive engineers or corrosion scientists.

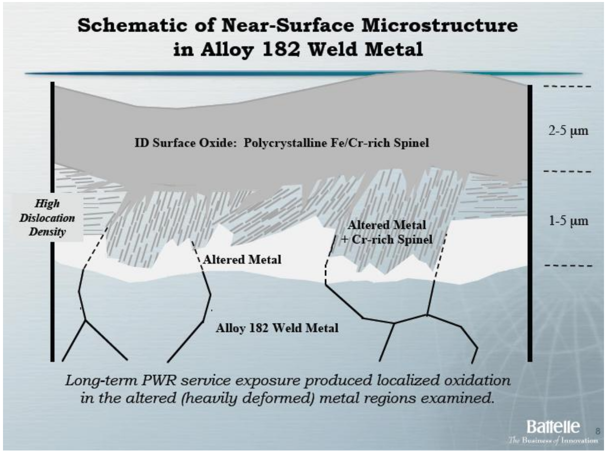

Fig. 1 Schematic of near surface microstructure of Ni base alloys [3]

In general, the underlying intent of most thoughtful investigations of crack initiation is to determine how a well-defined crack can form from a nominally smooth surface. Following idea can be used to refine the terminology to address such concepts [6]:

- Chemically short cracks(deeper crack has not formed).
- Mechanically small cracks, which are shallow surface cracks growing under plane stress conditions, or where linear elastic fracture mechanics cannot be applied with confidence.
- Metallurgically small cracks, which are cracks smaller than metallurgical features, e.g., the grain size.

Scientific definition of the crack initiation is a formation of a physically distinct geometry that will tend to grow in preference to its surroundings as a sharp crack. On the other hand, practical definition is a detectability that is likely to be achievable in in-situ autoclave investigations in the laboratory, e.g., ≈ 50 μm crack depth. [6]

Crack propagation comes from a stage of crack coalescence, which is described as the process of connecting or linking multiple smaller cracks into a single larger crack.

Fig. 2 describes schematically a process of crack initiation and propagation.[6]

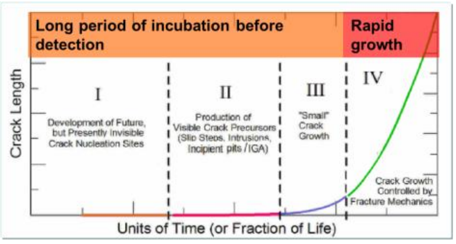

Fig. 2 PWSCC initiation and propagation of Alloy 600[4]

3. Case study of PWSCC initiation of Alloy 600 and 690

Plant operation experience of PWSCC cracking is described here. Unlike the Alloy 600 nozzle in the cold leg side, Alloy 690 was used for the hot leg drain nozzle from the beginning of operation in 1996 in a plant, as shown in Fig. 3.

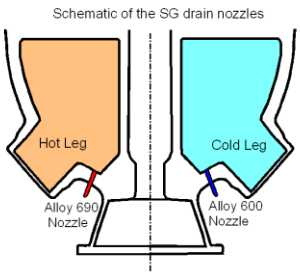

Fig. 3 Alloy 600 cold leg nozzle and Alloy 690 hot leg nozzle

The Alloy 690 nozzle has not shown any leakage as of December 2012. The two materials were exposed to the same primary coolant under at slightly different temperature (operating temperature of the Alloy 600 cold leg nozzle (T_{cold}) was 293 ^{o}C, and that of the Alloy 690 cold leg nozzle (T_{hot}) was 323^{o}C.

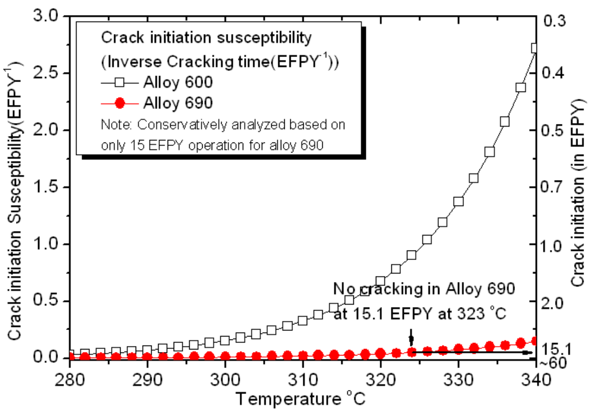

Fig. 4 Crack initiation susceptibility of Alloy 600 and Alloy 690 nozzle

Arrhenius equations for a crack initiation of Alloy 600 and 690 are described as below in the range of the maximum operating temperature at the pressurizer (340^{o}C) and minimum temperature at the cold leg nozzle (280^{o}C).

$1/C_{(Alloy\ 600)}$ = 2.18*1018 * exp(-210,000/8.31*T) for Alloy 600 ……………………………………………….….... (1)

$1/C_{(Alloy\ 690)}$ = 1.17*1017 * exp(-210,000/8.31*T) for Alloy 690 …………………………………….…………… (2)

Equation (1) and equation (2) for the crack initiation susceptibility of Alloy 600 and 690, respectively, with different rate constants, are depicted in Fig. 4. The PWSCC initiation of Alloy 600 is more susceptible than Alloy 690 at a given temperature, and the crack initiation time difference between the two alloys increases with temperature.

4. Summary

(1) PWSCC initiation and propagation process was described from chemical, mechanical and metallurgical view point.
(2) PWSCC initiation time of Alloy 600 and 690 from a plant operating experience was surveyed.
(3) Crack initiation time difference between the two alloys increases with temperature.

ACKNOWLEDGMENTS

This work was carried out as a part of the nuclear R&D program sponsored by the Ministry of Education Science and Technology (MEST)

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