Review of Irradiation Assisted Stress Corrosion Cracking of Austenitic Stainless Steels

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1. Introduction

Austenitic stainless steels used for PWR core internal components degrade in the environment of radiation and high temperature water during their long-term service. As they suffer from intergranular cracking at the neutron fluence over the critical value, this degradation mechanism termed irradiation assisted stress corrosion cracking (IASCC) is one of the hot issues in light water reactor (LWR) industry to aim at pursuing license renewal of commercial reactors. Much attention has been paid to an understanding of the IASCC mechanism, which is yet to be achieved. IASCC appears to be very similar to intergranular stress corrosion cracking (IGSCC) in view of intergranular cracking but the former differs from the latter because the former can occur even without corrosion [1]. Consequently, intergranular cracking of IASCC should be taken into account from mechanistic view points. The aim of this study is to analyze the IASCC susceptibility of austenitic stainless steels in view of material compositions and the environment, and hence to guide research directions to take in order to elucidate the IASCC mechanism.

2. Effect of material compositions

Given that the % IG cracking of stainless steels is independent of the bulk Cr content in slow strain rate tests in high purity water containing 8ppm DO at 289 °C, Chung [2] has indicated that IASCC resistance of the austenitic stainless steels is independent of the Cr content in the bulk. This finding challenges old belief that Cr depletion is likely to be the cause of intergranular stress corrosion cracking. Likewise, chemical analysis of failed baffle former bolt by IASCC has also shown the enrichment of Ni and S at the grain boundaries as shown in Fig. 1 [2]. Consequently, a map of IASCC resistance of stainless steels is suggested as a function of sulfur and carbon contents as shown in Fig. 2 [2]. From these facts, it is clear that a lower S concentration and a higher C concentration should enhance the IASCC resistance of stainless steels. However, it is yet to understand the role of sulfur and carbon in IASCC susceptibility.

3. Effect of the environment

Fujimoto et al.[3] has conducted a critical experiment where four austenitic stainless steels irradiated in a FBR and in a PWR were examined to investigate the effect of the irradiation test environment on IASCC. It should be

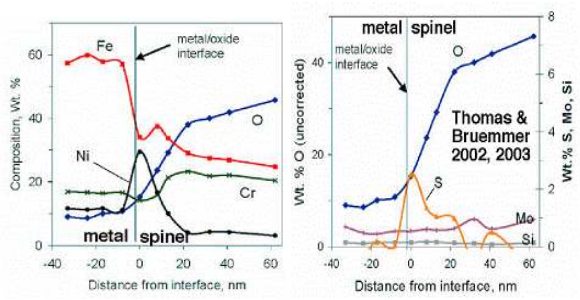

Fig. 1. Enrichment of Ni and sulfur at a grain boundary in a cracked PWR baffle former bolt [2].

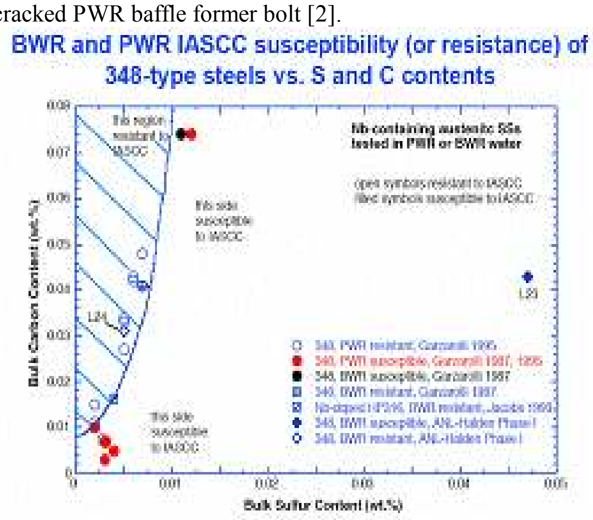

Fig. 2.A map of IASCC resistant stainless steels as a function of sulfur and carbon contents [2].

noted that the environment to which the stainless steels are exposed during irradiation is Na in a FBR and water in a LWR. Tensile properties and the radiation induced segregation (RIS) of the austenitic stainless steels are not so big different between irradiation in the FBR and PWR (Fig. 3) [3]. However, the austenitic stainless steels irradiated in the FBR had less hydrogen/helium gas concentration and less IASCC susceptibility compared to those irradiated in the PWR (Fig. 4) [3]. These facts show that hydrogen or helium coming from the water coolant plays some important role in IASCC of PWR core internal components although the role of hydrogen or helium in IASCC is not clearly understood. Thus, it is clear that RIS without hydrogen/helium has little effect on IASCC. However, the segregation of Ni and sulfur due to RIS in the presence of hydrogen/helium may enhance IASCC, for which experimental evidence is required.

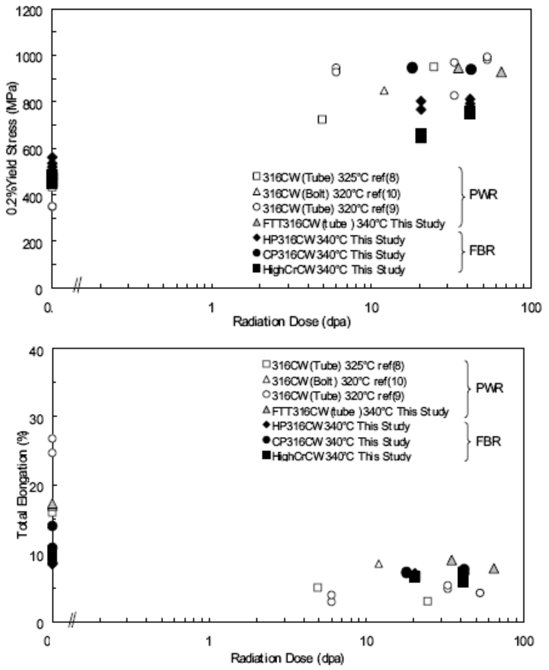

Fig. 3. Tensile properties of CW 316 stainless steels irradiated in a PWR and a FBR with radiation dose (dpa) [3].

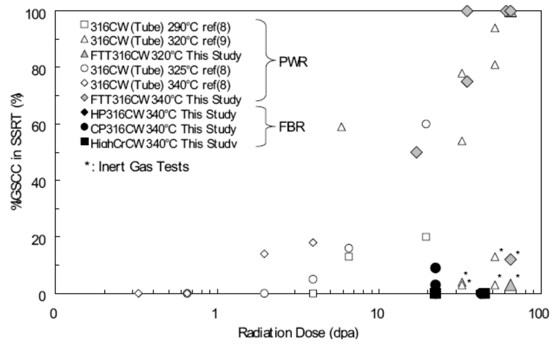

Figure 4 Relationship Between Radiation Dose and IG Ratio by SSRT Tests for Irradiated Materials in PWR & FBR.

Fig. 4. Intergranular cracking ratio of the irradiated 316 stainless steels in a PWR and a FBR as a function of radiation dose [3].

4. Suggestions for IASCC research

IASCC of austenitic stainless steels differs from IGSCC because IASCC occurred even in inert gas environment at the fairly high radiation dose of 65 dpa [3]. It is, therefore, obvious that the IASCC mechanism is explored in view of mechanistic cracking instead of corrosion cracking. Irradiation tests of four kinds of austenitic stainless steels in a PWR and a FBR show definitively that IASCC is kind of hydrogen cracking. Concentration of sulfur and Ni at the grain boundaries will enhance hydrogen cracking there because hydrogen diffusing fast through Ni interacts strongly with sulfur. Consequently, future work on IASCC should focus on the effect of hydrogen on intergranular cracking of austenitic stainless steels.

ACKNOWLEDGEMENTS

This work has been carried out as part of the Nuclear R&D program supported by Ministry of Knowledge Economy, Korea.

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