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MECHANISTIC UNDERSTANDING OF IRRADIATION ASSISTED STRESS CORROSION CRACKING

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Abstract
Irradiated austenitic alloys are susceptible to degradation in high temperature water by irradiation assisted stress corrosion cracking (IASCC). This paper will provide a mechanistic understanding of the IASCC process to date, incorporating the most recent observations and experimental results.

1. Introduction

While a general understanding of the process is emerging, there are several interesting observations that may now be incorporated into a complete description of the mechanism. It is now known that the local stress at the grain boundaries at sites of dislocation channel impingement plays a critical role. The composition of the surface oxide over the grain boundary is believed to be a key factor, as are oxides that form down the grain boundary. Most recently, grain boundary migration has been observed in irradiated stainless steels. Other factors such as the presence of second phases near grain boundaries and the overall composition of the steel can significantly affect the cracking susceptibility. This paper will focus on recent experimental results showing that oxidation of grain boundaries is a precursor to IASCC, and that IG cracking occurs by fracture of the heavily oxidized boundaries.

2. Results

Experiments were conducted on miniature (5 mm x 3.5 mm x 0.8 mm) four-point bend samples of 304 SS irradiated to 5.4 or 69 dpa in the BOR-60 reactor at 320°C and a damage rate of ~1 x 10^{-6} dpa/s. The samples were tested in 320°C PWR primary water (1000 ppm-B, 2 ppm-Li), 35cc/kg H_2. Samples were loaded dynamically at a under constant strain rate (4.3×10^{-8}/s) in increments of 0.1 of the yield stress (0.1YS) of the irradiated sample. The separation of oxidation in simulated PWR primary water at 320°C followed by straining in Ar at the same temperature. Pre-oxidation without application of load in simulated PWR primary water followed by straining in high temperature Ar clearly showed the effect of exposure time on GB oxidation and the impact on lowering the stress to initiate crack. Exposure of SA304 SS (5.4 dpa) for 210 h in high temperature water initiated the cracks at 0.6YS in Ar whereas the companion sample of same dose level exposed to 1010 h in primary water cracked at low stress level 0.5YS in Ar. The long-term exposure in water leads to oxidation of the grain boundary that ultimately lowering the crack initiation stress, Figure 1.

While pre-exposure experiments followed by straining in high purity Ar has shown that grain boundary oxidation is a necessary and sufficient condition to initiate IASCC, the application of stress during exposure results in more and longer cracks. Both the surface crack length and the crack length per unit area are much greater than that in the pre-exposed and subsequently tested samples in Ar. Stress accelerated oxidation and subsequent cracking is probably the main reason for larger average crack length, which also likely results in greater crack depths. The depth of cracks in the samples stressed during oxidation can exceed 10,000 nm while of those tested in the pre-exposed + straining in Ar had a maximum depth of 460 nm. There was no evidence of cracking upon straining of an unoxidized SA304 SS (69 dpa) sample to 0.8YS in high temperature Ar whereas the same dose level sample pre-oxidized in water for 210 h followed by straining in Ar cracked at much lower stress level of 0.5YS. The DC-GB intersections and/or triple junction sites can promote cracking only when the GB is oxidized.

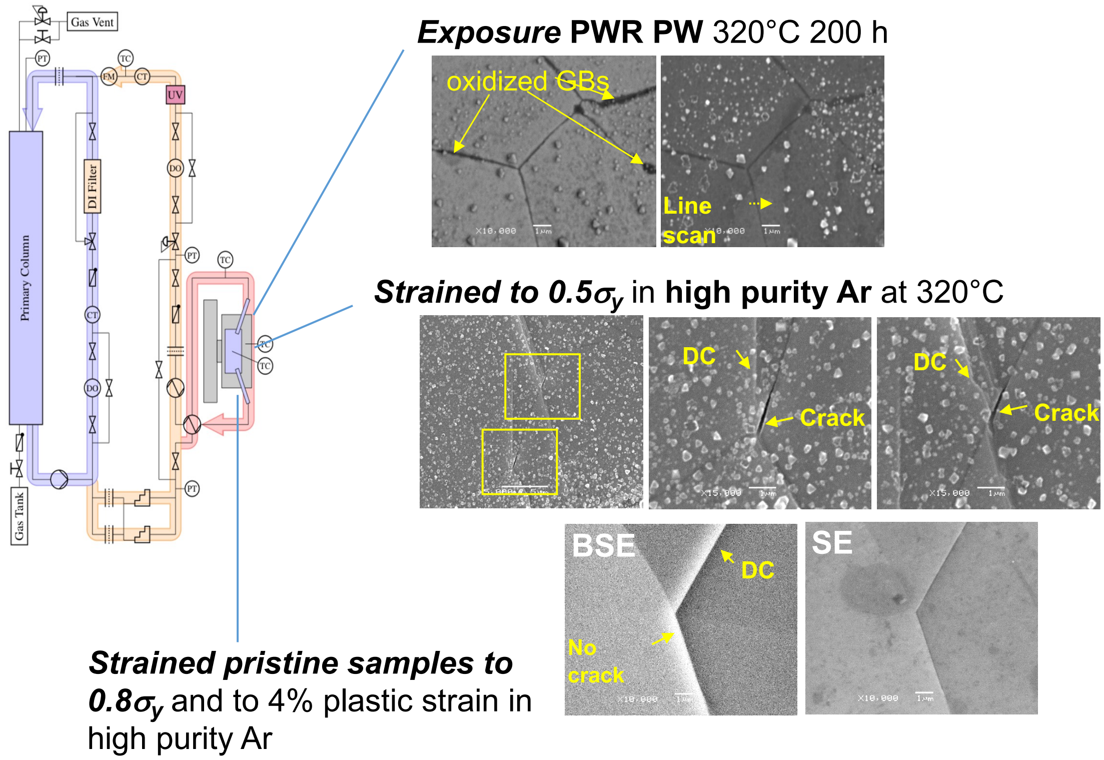

Figure 1. Separation of oxidation and straining steps to isolate the role of grain boundary oxidation in IG cracking in 69 dpa 304 SS

3. Conclusions

Separation of oxidation and straining steps confirms that GB oxidation is both a necessary and sufficient condition to initiate IASCC. The decrease in stress to initiate crack with long-term exposure substantiates the role of GB oxidation on IASCC. The lack of IG cracking in an irradiated but non-oxidized sample tested in Ars confirm that the samples are not inherently susceptible to IG cracking and that oxidized GBs serve as initiation sites for IG cracking.

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