Review on fractography of baffle former bolt removed from pressurized water reactors

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1. Introduction

The reactor internals of pressurized water reactors (PWRs) are mostly fabricated from solution annealed austenitic stainless steels. The austenitic stainless steels has good resistance to stress corroson cracking(SCC) and fracture toughness in the PWR primary water environment. But the austenitic stainless steels is not immune to the irradiation assisted stress corrosion cracking (IASCC). IASCC of PWR internal baffle former bolt has been reported in Europe and United States since 1989. UT indication in baffle former bolt in Kori 1 was also reported in 2016. Fracture surface of baffle former bolt removed from pressurized water reactors showed combination of intergranular(IG) SCC, transgranular(TG) SCC, IG-TG mixed mode cracking and dimpled rupture. Some baffle former bolt showed 100 % IG cracking while absolutely no IG cracking on fracture surface. Up to now, no systematic explanations on the fractography were given in published literatures.

2. Review on fractography of SCC

In this work, we did literature review on IGSCC and TGSCC of FCC alloy such as stainless steel and Cu alloy and Alloy 690 to understand fractography of austenitic stainless steel in PWR primary water.

2.1 IG to TG transitionin SCC

To understand the SCC mechanism, SCC test of Cu-30Au noble-metal alloys performed in 0.6M NaCl solution with virtually constant load [1]. Chen[1] reported that at low values of stress, failure occurred by brittle intergranular cracking, and at high values of stress, failure occurred by brittle transgranular cracking. Chen[1] concluded that the electrochemical contribution to the SCC of Cu-30Au in 0.6 M NaCl is the same for both IGSCC and TGSCC and that the mode of fracture is dictated by the magnitude of the applied stress. However, Chen[1] did not explain why stress determines cracking mode.

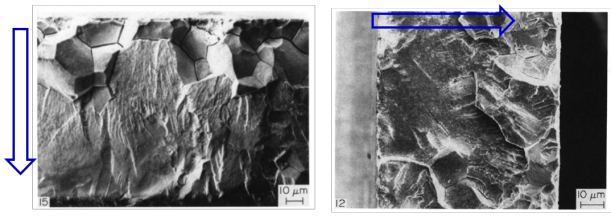


Fig. 1 Facture mode transition in Cu-30Au with crack growth [1].

2.2 TG to IG transition in SCC

To understand the SCC mode of austenitic stainless steel, influence of cold work in the range 2.3 to 56 pct on SCC properties of Types 304 and 316 stainless steels in boiling $MgCl_2$ solution at 154°C was investigated using a constant load method [2]. In both materials, SCC initiation was in TG mode. Transition in SCC mode from TG to IG, as the crack proceeds, was observed at all cold work levels in 316 stainless steel and at cold work levels of 26 % and 56 % in 304 stainless steel. Both prestraining and increase in the initial applied stress facilitated the transition in crack morphology to intergranular mode. Increased tendency to intergranular SCC at high applied stresses and in cold worked specimens appears to be mechanistically analogous. Muraleedharan [2] did not explain why stress determines cracking mode.

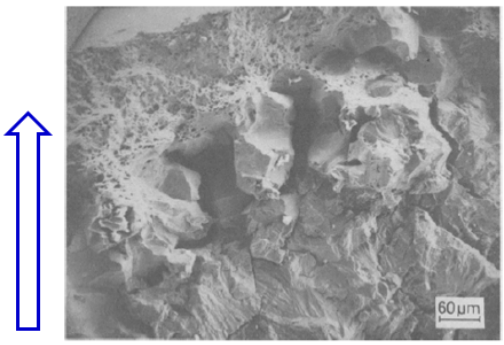
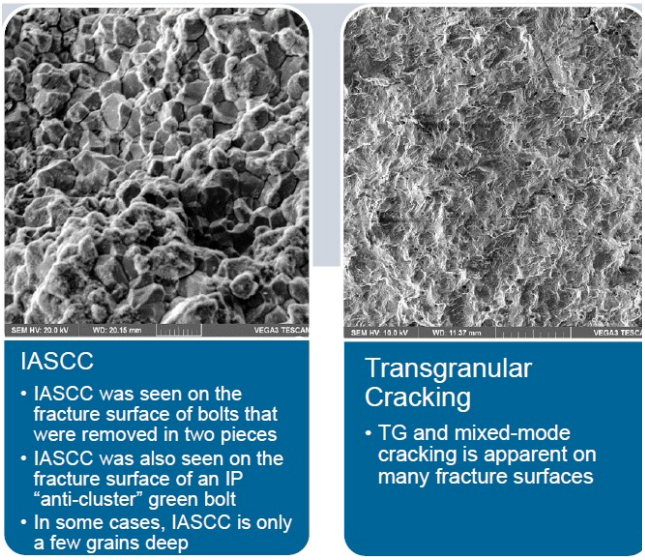


Fig.2 Facture mode transition in Type 316 stainless steel with crack growth [2].

3. Review on fractography of IASCC

EPRI performed extensive study on IASCC of baffle former bolt in PWR [3]. Fracture surfaces can contain regions of IG-SCC, TG-SCC, Fatigue, and Ductile Overload. Extent of IG cracking found to vary from 4% to 66%. Extent of cracking mode varies bolt-to-bolt. No obvious correlation of extent of each cracking mode with bolt location or expected dose. EPRI[3] just reported what they observed without detailed explanation.



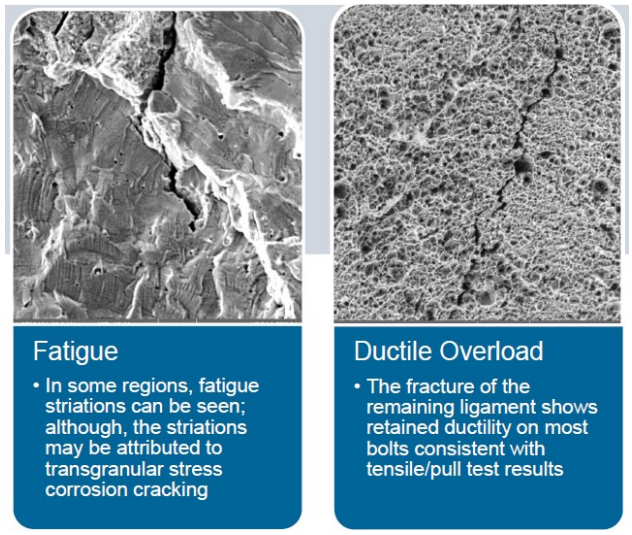


Fig. 3. Fracture mode of IASCC in austenitic stainless steel [3].

4. Conclusions

IASCC mode of austenintic stainless steel as well as SCC mode of FCC alloy were reviewed. IASCC and SCC mode transition were explained in terms of crack growth rate vs stress.

REFERENCES

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[2] P. Muraleedharan, J. B. Gnanamoorthy and P. Rodriguez, Corrosion Science, Vol. 38, No. 7, pp. 1187-1201. 1996
[3] Joint EPRI MRP/PWR Owners Group Baffle-Former-Bolt Focus Group Update Industry-NRC Materials Exchange Meeting, Rockville, MD May 23, 2017