Development of IASCC Test Facility for Neutron-irradiated Materials

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1. Introduction

Irradiation assisted stress corrosion cracking (IASCC) has been regarded as the main cause for intergranular cracking incidents in reactor vessel internals (RVIs) in light water reactors (LWRs). IASCC was reported in a fuel rod in the 1960s, a control rod in the 1970s, and a baffle former bolt in recent years. For a proactive management of IASCC of these components, a lot of work has been performed in boiling water reactors (BWRs) [1, 2]. From these works, IASCC mechanism and its relation to radiation-induced segregation (RIS), neutron fluence, and applied stress were proposed to describe IASCC behavior of RVIs in BWRs.

However, the IASCC mechanism of RVIs in pressurized water reactors (PWRs) is not fully understood yet as compared with that in BWRs owing to a lack of reliable data [3, 4]. Recently, worldwide efforts have been made to investigate the IASCC susceptibility of RVIs in PWRs. The aim of this work is to review recent test methods for evaluation of IASCC susceptibility of neutron-irradiated stainless steels, and to establish IASCC test facility for assessment of life time of RVIs of Korean PWRs.

2. Recent Technologies of IASCC Evaluation

This section describes recent techniques used to evaluate the IASCC initiation and propagation of neutron-irradiated stainless steels reported in previous works.

One method of testing irradiated specimens is to place the specimens under a constant load and then record the time until cracking occurs. This method has usually been used for assessment of time-to-failure and threshold stress of stress corrosion cracking (SCC). The constant load test can be performed using several different specimen geometries but are generally performed using either constant load tensile, C-ring or O-ring specimens. In addition, those specimens should not undergo consequential stress relaxation, either by demonstrating that little relaxation occurs or actively loading, e.g., by spring loading, differential pressure or external loading by electric servo-motor.

Table 1 presents recent test methods for SCC or IASCC initiation studies of worldwide research groups. KENO system developed by Andresen et al. can accommodate 150 specimens in an autoclave, and apply constant load to the specimens by pressure difference between one end of a round-bar tensile specimen and the opposite end [5]. It is interesting that the rupture time of the specimen can be accurately recorded by ball counter.

Maeguchi et al. [6] and Takakura et al. [7] also developed constant load test methods using air cylinder to maintain a constant load to specimens for evaluating time-to-failure of SCC and IASCC. They also adopted auto-detection devices for rupture of C-ring or tensile specimens. Recently, Toloczko et al. [8] adopted a direct-current potential drop method (DCPD), a well-established in-situ method of crack growth rate measurement, to monitor SCC initiation and found that DCPD with multiple channels is also applicable to detect micron-scale crack initiation on each gauge surface of 30 specimens. As a part of OECD Halden reactor project, in-pile test methods of IASCC initiation and growth are also developed using a metallic bellows loading devices. The failure of specimen can be detected from collapse of bellows and movement of LVDT magnetic core placed in in-core test rigs.

3. Requirement of IASCC Test Facility

From literature survey and benchmark studies, the main requirements for test method and facility to evaluate IASCC susceptibility and time-to-failure of neutron-irradiated materials are summarized as follows,

(1) To handle neutron-irradiated materials having high fluence level, the IASCC test equipment should be placed in a concrete or lead shielded hot cell. In addition, any leakage of test solution from the autoclave and water loop system is strictly prohibited.
(2) Test environment should be well-controlled with flowing water simulating a primary water chemistry of PWRs, and carefully monitored during the test.
(3) To obtain life data, i.e., time-to-failure vs. applied stress, applied load to test specimens should remain constant during whole test duration.
(4) Experimental techniques for in-situ monitoring or auto-detecting IASCC initiation or rupture of each of test specimens should be adopted.
(5) For more efficient life time assessment using a statistical approach, larger number of specimens needs to be tested at the same batch with sufficient replicates to provide a statistically confident result.
(6) For more compact design of autoclave and load train, smaller size of test specimen is preferred while maintaining reproducible and reliable result.

Table I: Recent test methods adopted or applicable to IASCC evaluation

Category	Method	Specimen	No. of samples	Load control/type	Data	Remarks
Initiation	GE KENO	round-bar tensile	150 specimens (3 manifold - 50 specimens)	constant load by pressure diff.	failure time vs. stress	auto-detection of rupture by ball counter
	MHI C-ring	C-ring	3 specimens	constant load by air cylinder	failure time vs. stress	auto-detection of rupture by laser displacement monitor
	MHI uniaxial load test	1/4 tubular, plate	39 specimens (3 test chamber - 13 specimens)	constant load by air cylinder	failure time vs. stress	auto-detection of rupture by air leak/displacement
	PNNL tensile	round-bar	total 30 specimens (~16 with DCPD)	constant load by servo motor	DCPD V with time, failure time vs. stress	DCPD monitor, displacement
	Tapered tensile	tapered bar, tapered plate	1 specimen per spring-unit	constant load by springs (or motor)	failure time vs. stress	determine threshold stress from small No. of specimens
	Halden tensile	round-bar tensile	1 specimen per bellows-unit	constant load by bellows	failure time vs. stress	auto-detection of rupture by LVDT magnetic core, In-core test
	IMTL CERT	plate	4 specimens	constant load by motor	crack length per area	hot cell test
CGR	Halden CGR	CT	1 specimen per bellows-unit	constant load by pressurized bellows	DCPD V with time	CGR monitory with DCPD, hot cell test, pivot loading unit
	IMTL CGR	round-CT	1 specimen per load train	load control by motor	DCPD V with time	CGR monitory with DCPD, hot cell test, fixtures for manipulator works (positioning, welding)

According to the requirements of IASCC test facility from literature review and benchmark of state-of-the-art technologies, the Nuclear Materials Safety Research Division of KAERI has started a 3-year project to develop detail design of IASCC test facility of highly irradiated stainless steels, and will continue the next project to construct the test facility, in close co-operation with the Irradiated Materials Examinations Facility (IMEF) of KAERI.

4. Summary

From literature review and benchmark studies on recent technologies for IASCC evaluation of highly irradiated stainless steels, the requirements to establish IASCC test facility were drawn. According to the requirements, IASCC test facility for assessment of life time and integrity of RVIs in Korean PWRs will be designed in detail and constructed in hot cells of KAERI.

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