A round-robin project in Japan for the evaluation of nondestructive responses of natural flaws

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Abstract

This paper introduces the current status of a round-robin project aiming at gathering non-destructive data of natural flaws. The project, which was launched in 2009, prepared specimens containing artificial stress corrosion cracks and thermal fatigue cracks, and served the specimens to a round-robin test to gather non-destructive data. A total of 12 universities and research institutes have participated to the round-robin test. Some of the specimens are already destroyed to confirm the true profiles of the cracks, whereas others remain undestroyed. All the data are presented at a dedicated webpage, together with the results of the destructive tests, so that they are freely available for anybody.

Keywords: thermal fatigue crack, stress corrosion cracking, electromagnetic nondestructive testing, ultrasonic testing, numerical modeling

1. Introduction

Maintaining the safety of structures is one of the most important issues for the energy, enbironment and sustainable economy. The Periodic nondestructive testing and evaluation (NDT&E) is indispensable for assuring the safety of structures. Defects in important structures have to be detected in their early stage, and their effects on the integrity of the structures are needed to be evaluated in order to discuss the suitable maintenance activities. A large number of studies have been carried out for the R&D of techniques for the NDT&E of flaws and degradations appearing in nuclear power plants. One of important targets of the techniques is a crack such as fatigue and stress corrosion cracks because of its serious effect on structural integrity. However, most studies have a common problem. That is, they often use artificial slits for their validations, although the responses of an artificial slit to non-destructive testing are not always similar to that of an actual crack. Figure 1 presents the results of a survey counting the number of studies dealing with artificial slits, fatigue cracks, or stress corrosion cracks for the development of nondestructive testing and evaluation methods. The survey targeted studies published in three international journals whose scope is nondestructive testing and evaluation, that is, NDT&E International, Journal of Nondestructive Evaluation, and Nondestructive Testing and Evaluation. A glance at the figure confirms that most studies use artificial slits for evaluating or demonstrating their methods.

In general, the response of a real crack is smaller than that of an artificial alit even though their profiles, namely depth and length, are almost same. Studies so far have pointed out that this would be due to the small opening of the actual crack from the viewpoint of ultrasonic-based nondestructive testing methods (Frandsen et al. 1975), and would be due to the electrical contact of the crack surfaces from the viewpoint of electromagnetic-based nondestructive testing methods (Yusa and Hashizume, 2009). Several recent studies have pointed out a possible effect of oxides on signals(Uchimoto et al., 2011, Horinouchi et al., 2011). However, there are very few studies quantitatively discussing the discrepancy between artificial slits and actual cracks. One of the reasons for this is very little commonly available information about real cracks. To the best of the authors' knowledge, all benchmark data proposed so far deals with artificial slits (Thompson, 2002, Harrison et al., 1996, Takagi et al., 1994).

On the basis of the background above, a research project was launched in 2009 (Yusa et al., 2010). The research project aimed to gather non-destructive testing signals due to stress corrosion cracks and make the signals openly available for anybody in order to promote studies on the problem. The project prepared austenitic stainless steel plates containing stress corrosion cracks artificially introduced using various conditions. They were then utilized for round-robin tests to measure non-destructive testing signals by using various methods. More than ten research groups utilizing different NDE techniques participated to the project. A dedicated webpage was prepared to present the signals together with other data characterizing the stress corrosion cracks such as the results of metallographic tests.

The present paper reports the latest situation and results of the round-robin test. An important update is that three type 304 stainless steel plate specimens containing eight artificially introduced thermal fatigues (Kemppainen et el., 2003a, Kemppainen et al., 2003b) in total were offered to the round-robin test. Figure 2 presents the macroscopic photograph of the surface of one of the fatigue cracks. The specimens were also utilized for a round-robin test and measured by several research groups.

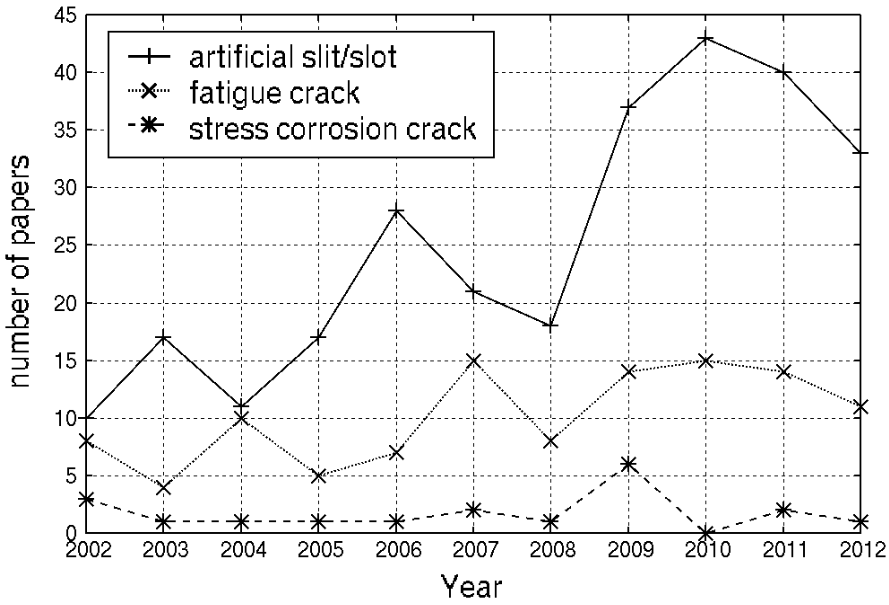

Figure 1. The number of papers dealing with artificial slit, fatigue cracks, or stress corrosion cracks. The increase in the number of papers stems mainly from the increase in the number of papers published in one of the journals.

Figure 2. Microscopic photograph of the surface opening of one of the thermal fatigues offered to the project. Pictures with a higher resolution are available at the webpag

2. Overview and the current status of the project

2.1 Specimens offered

The project initially prepared seven specimens containing 12 artificial stress corrosion cracks listed in Table 1. TP03 is made from type 304 austenitic stainless steel; others are type 316 austenitic stainless steel. All the cracks were introduced by bending the plate to impose tensile stress on the surface and then soaking it in a corrosive solution. As the table shows the specimens have different thicknesses, corrosive solutions, and initial cracks so that the cracks introduced have a variety of profiles to reflect general situations. All except TP03 are already destroyed to confirm the actual profiles of the cracks; others remain undestroyed. The destructive tests were carried out to confirm the cross-sectional profile of the cracks at planes perpendicular to the cracks because in general a stress corrosion crack has multi-blanched complicated three-dimensional profile.

Three type 304 austenitic stainless steel specimens containing total of nine thermal fatigue cracks, which are listed in Table 2, were offered to the project in 2011. The thermal fatigue cracks were artificially introduced by cyclic thermal loading due to induction heating and water cooling. No initial crack was used to introduce the thermal fatigue cracks. All the specimens have been destroyed and the profiles of the thermal fatigue cracks revealed. The destructive test observed the boundary profile of the crack because the three-dimensional structure of thermal fatigues should be less complicated than that of stress corrosion cracks. Additional tests were carried out to confirm the cross-sectional profile at the center.

2.2 Availability of the data

The non-destructive data, as well as the results of the destructive tests, are freely downloadable from the webpage prepared under the official website of the Japan Society of Maintenology (http://www.jsm. or.jp/) as shown in Fig. 3. The webpage is prepared both in English and Japanese. The non-destructive data are basically presented in a text format, except several cases, so that they are easily readable for anybody.

It should be noted that neither this project nor the Japan Society for Maintenology, which manages the experimental data, imposes any restrictions on the use of the data. The data will be freely downloadable and available for anybody; however, copyright of several pictures belongs to the Japan Society for Maintenology. Furthermore it is not necessary for research institutes participating in this project to provide all measured results. For example, if a research institute measures data by more than one experimental condition (for instance using several probes), the institute is required to provide data measured with one of the conditions, though other data are available for their own study independent of this project.

Table 1 List of specimens containing stress corrosion cracks

ID	Material	Dimension [mm]	Thickness [mm]	Number of SCCs (surface length [mm])	Corrosive Solution	Initial Crack
TP01	SUS316	150×150	16	3 (26, 28, 29)	Tetrathionate acid	EDM
TP02	SUS316	150×150	16	3 (14, 24, 17)	Tetrathionate acid	Fatigue
TP03	SUS304	300×300	25	2 (28, 33)	Tetrathionate acid	EDM
TP04	SUS316	205×105	13	1 (18)	Polythionic acid	EDM
TP05	SUS316	200×100	9	1 (21)	$MgCl_2$	None
TP06	SUS316	200×100	9	1 (19)	$MgCl_2$	None
TP07	SUS316	200×100	9	1 (14)	$MgCl_2$	None

Table 2 List of specimens containing thermal fatigue cracks

ID	Material	Dimension [mm]	Thickness [mm]	Number of cracks (surface length [mm])
W286	AISI304	250×150	25	1 (14)
W316	AISI304	250×150	25	5 (4, 10, 20, 22, 1)
W318	AISI304	250×150	25	2 (12, 7)

Table 3 Non-destructive signals of the artificial stress corrosion cracks

Method	Measured by
Nonlinear ultrasonic testing	Ultrasonic Materials Diagnosis Laboratory
Phased-array TOFD	Institute of Nuclear Safety System, Incorporated
Eddy current testing	Nihon University
Eddy current testing	Zhejiang University
Eddy current testing	Institute of Fluid Science, Tohoku University
Eddy current testing	Xi'an Jiaotong University
Eddy current testing	Japan Power Engineering and Inspectin Corporation
Eddy current testing	Mitsubishi Heavy Industry
Eddy current testing	Department of Quantum Science and Energy Engineering, Tohoku University
Direct current potential drop	Okayama University
Induced current potential drop	Toyota Central R&D Labs.
Visual testing	Department of Quantum Science and Energy Engineering, Tohoku University
Destructive Test	Department of Quantum Science and Energy Engineering, Tohoku University

Table 4 Non-destructive signals of the artificial thermal fatigue cracks

Method	Measured by
Nonlinear ultrasonic testing	Ultrasonic Materials Diagnosis Laboratory
Phased-array TOFD	Instituge of Nuclear Safety System, Incorporated
Eddy current testing	Department of Quantum Science and Energy Engineering, Tohoku University
Eddy current testing	Nihon University
Eddy current testing	Institute of Fluid Science, Tohoku University
Eddy current testing	Japan Power Engineering and Inspectin Corporation
Visual testing	Trueflaw
Penetrant testing	Trueflaw
Destructive Test	Trueflaw

3. Conclusing remark

This paper introduced a research project focused on the NDT&E of cracks. As mentioned above some of the specimens remain undestroyed and are still available. We welcome any research institutes worldwide that are interested in measuring the specimens using their method/s.

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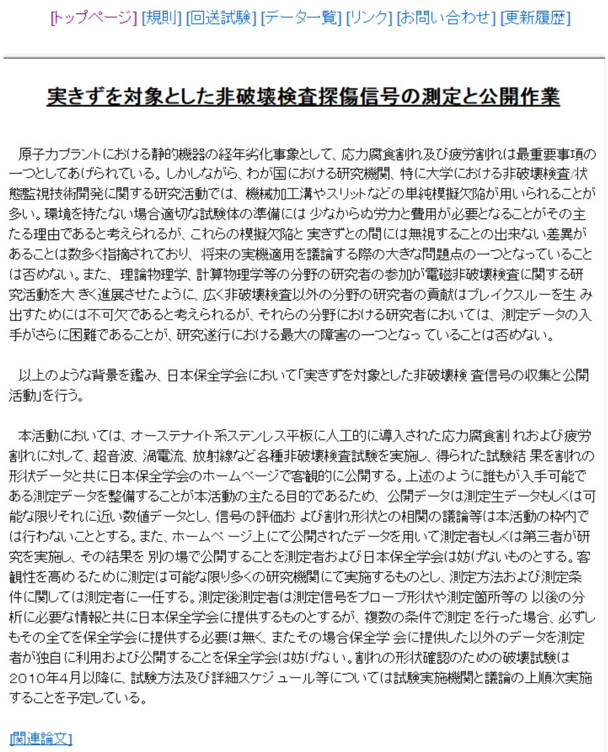
(a) Link to the project situated at the top page of Japan Society of Maintenology website



(b) Top of the project webpage

Figure 3. Webpage prepared for the project

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