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Original Article

ACOUSTIC EMISSION CHARACTERISTICS OF STRESS CORROSION CRACKS IN A TYPE 304 STAINLESS STEEL TUBE

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ABSTRACT

Acoustic emission (AE) is one of the promising methods for detecting the formation of stress corrosion cracks (SCCs) in laboratory tests. This method has the advantage of online inspection. Some studies have been conducted to investigate the characteristics of AE parameters during SCC propagation. However, it is difficult to classify the distinct features of SCC behavior. Because the previous studies were performed on slow strain rate test or compact tension specimens, it is difficult to make certain correlations between AE signals and actual SCC behavior in real tube-type specimens. In this study, the specimen was a AISI 304 stainless steel tube widely applied in the nuclear industry, and an accelerated test was conducted at high temperature and pressure with a corrosive environmental condition. The study result indicated that intense AE signals were mainly detected in the elastic deformation region, and a good correlation was observed between AE activity and crack growth. By contrast, the behavior of accumulated counts was divided into four regions. According to the waveform analysis, a specific waveform pattern was observed during SCC development. It is suggested that AE can be used to detect and monitor SCC initiation and propagation in actual tubes.

1. Introduction

Because mechanical structures are getting bigger and more efficient, the component materials demand high strength and toughness as well as increased corrosion and thermal resistance. Furthermore, the working environment for mechanical structures is getting severe. Therefore, to ensure the integrity of structural materials, regular inspection of these materials is

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increasingly emphasized. The state of structural components is monitored through a periodic inspection using nondestructive tests such as radiographic test, ultrasonic test, etc. However, these tests have certain limitations, and therefore, during an in-service inspection not all existing defects can be identified. Because cracks can only be detected after they have grown large enough, preventive detection is difficult. These disadvantages may be reduced by remote and continuous monitoring. Acoustic emission (AE) is one of those solutions. AE is a nondestructive technique based on the rapid release of energy within a material generating transient elastic wave propagation. It can detect very tiny defects in the structural material and has a relatively low test cost.

Many authors have reported the application of AE for evaluating stress corrosion cracks (SCCs) and pitting corrosion using slow strain rate test (SSRT) or compact tension (CT) specimens [1–4]. They found that SCC occurred in specific combinations of three essential conditions, namely, tensile stress or strain of a sufficient level, an aggressive electrolyte, and a susceptible material. The synergetic combination of mechanical and electrochemical processes could lead to two different modes of crack propagation, namely, (1) intergranular SCC in which cracks advance along crystal grain boundaries and (2) transgranular SCC in which cracks advance through crystal grains [5]. Whatever the SCC mechanism is, the AE signals show similar parameters and amplitude distribution [6]. Many studies have reported on the characteristics of AE signals generated by SCCs and pitting corrosion [1,3–12]. Parameters of AE signals from SCCs were studied by Leinonen et al [3], Alvarez et al [6], Sung et al [7], Shaikh et al [11], and Perrin et al [12]. Fast Fourier transform analysis of AE waveforms in SCCs was studied by Chang et al [4] and Kovac et al [5]. Mazille et al [1], Fregonese et al [8], and Xu et al [9] studied AE signals generated in pitting corrosion. Although many studies were carried out on corrosion and cracking, their exact characteristics are not revealed clearly. Moreover, because the previous studies were performed on SSRT or CT specimens, rather than on real tubes used in nuclear power plants, it is difficult to make certain correlations between AE signals and behaviors of SCC in a real tube. Therefore, it is necessary to conduct the test with a tube in similar SCC environments and analyze the AE signal behavior, which transients during the SCC process.

In this study, we made SCCs in a real 304 austenitic stainless steel tube using our own designed equipment system, and a specific AE signal pattern for the SCC process was observed and analyzed.

2. Materials and methods

2.1. *Materials and equipment*

The dimensions of the AISI 304 austenitic stainless steel tube specimen (from POSCO, Pohang Steel Corporation, Korea) is as follows: diameter, 89 mm; thickness, 7.6 mm; and length, 150 mm. The composition and mechanical properties of the specimen are presented in Table 1. The inner surface of the tube was welded by gas tungsten arc welding to give the specimen residual stress (Fig. 1). According to previous studies

Table 1 – Chemical composition (wt%) and mechanical properties of the AISI 304 stainless steel.

Alloy element	C	Si	Mn	P	S	Cr	Ni
Composition	0.005	0.12	1.65	0.029	0.008	18.23	8.16

Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)
410	669	66.5

[6,13], the maximum residual stress is formed at the heat-affected zone. In general, the welding zone is the most sensitive region for SCC [14], because δ-ferrite is transformed in the fusion line and $Cr_{23}C_6$ is partially distributed in the grain boundaries [15].

To make an SCC, the AISI 304 tube was installed in our own designed equipment system, and was filled with a mixture of 1M Na_2S and 4M NaOH aqueous solution to simulate a corrosive environment. The amount of corrosive aqueous solution added was 50% of the volume of the tube specimen. Fig. 2 shows the test equipment layout and a cross section of the tube specimen.

To reproduce environmental conditions similar to that of a nuclear power plant, the tube was heated on the outer surface by a heating coil. The maximum temperature and pressure were measured as 383°C and 73 bar (Fig. 3).

2.2. *AE testing setup*

The system for recording and analyzing the AE signals included a four-channel data-acquisition instrument, storage media, sensor, and amplifier. The data-acquisition instrument was designed and manufactured by Physical Acoustics Corporation (PAC). The sensor was also manufactured by PAC. The sensor has a 400-kHz resonance frequency for the high-temperature purpose, with a maximum operation temperature of 500°C. The sensor output was amplified by a gain of 40 dB using a 1,222-charge preamplifier. A threshold level of 40–45 dB was set as a float type that can control the sensitivity of detection by keeping the voltage threshold of detection above the average background noise to minimize noise.

One high-temperature sensor was installed on each side of the flange. Once the signal had been detected by the sensors, the data were sent to the acquisition instrument and then stored immediately in the specific storage. The AE data from the specimen were filtered from electrical and environmental noise based on parameter characteristics, which have lower amplitude values than environmental noise. To distinguish the AE signals from the mechanical noise, the noise signal was

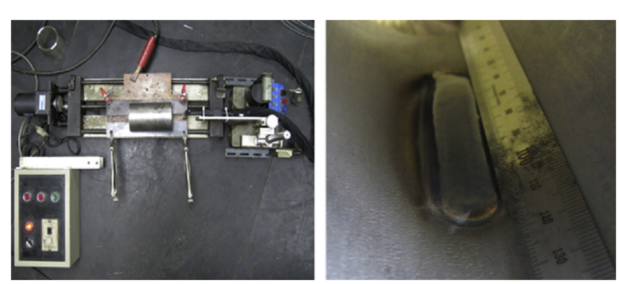

Fig. 1 – Equipment for gas tungsten arc welding and the welding bead (inner surface of tube).