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High Temperature Corrosion Behaviors of Carbon Steels by A Pressurized Water

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Abstract. The long-term corrosion resistances for the carbon steels have been investigated under high temperature pressurized water atmosphere, in the conjunction with the analysis of nondestructive properties by the ultrasonic wave. The corrosion test for carbon steels was carried out at the temperature of 200 °C under a water pressure of 10 MPa. The corrosion test cycles for carbon steels were changed up to 65 weeks. The mechanical properties of carbon steel suffered from the corrosion cycle were investigated by a tensile test, attaching an acoustic emission sensor on the test sample. The tensile strength of carbon steels greatly decreased beyond the corrosion cycle of 35 weeks, accompanying the increase of weight loss by the creation of corrosion damages. The attenuation coefficient of carbon steels by the ultrasonic wave increased with the increase of corrosion cycles.

Introduction

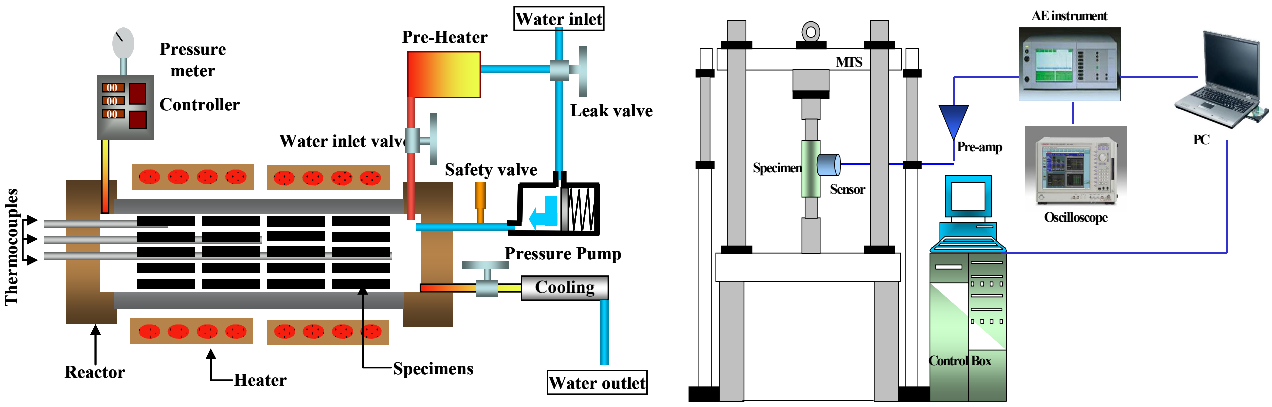
The carbon steel has been extensively studied for the integrity of principal structure materials in the nuclear power plant system such as cooling device, pressure vessel and steam generator tube. [1,2] The corrosion resistance of carbon steel is emphasized for the operational efficiency and the sound safety in the feeder pipes, due to the continuous driving of cooling fluid. The material life of carbon steel is greatly affected by the creation of stress corrosion crack (SCC) and its propagation under the corrosion environment. [3] For the effective maintenance of carbon steel pipes, it is very important to inspect the local wall thining by the corrosion or erosion. The wall thining of carbon steel pipe was greatly caused by the flow-accerlerated corrosion (FAC) in the environmental atmosphere exposed to the flowing water or the wet steam. [4] The majority of R & D research for the corrosion damages of carbon steels was mainly focused on the evaluation of mechanical properties in the various operating environments. However, it is difficult to inspect the continuous corrosion behavior at the real time, due to the long-term test period. The approach of nondestructive technique can be regarded as another way for examining the wall thining of pipe structures as well as the degree of corrosion damages. [5,6] The acoustic emission technique is also recognized as a useful method for the on-line monitoring of microscopic failure mechanism and the position confirmation of damaged portion in the structure.

The purpose of present study is to investigate the long-term corrosion resistances for the carbon steels under high temperature pressurized water atmosphere. Especially, the effect of corrosion cycle on the mechanical properties of carbon steels was examined, in the conjunction with the analysis of corrosion damages by the ultrasonic wave and the acoustic emission techniques.

Experimental procedures

The materials used in the corrosion experiment were a commercial seamless carbon steels (ASME A106) for a piping tube in the nuclear power plant. Fig. 1 shows the schematic diagram for high temperature corrosion test system designed by our research group. The corrosion test samples were mounted in a tube shaped reactor of corrosion test loop, in which the water pressure is automatically controlled by the inlet or outlet valve. The corrosion test for carbon steels was conducted at the temperature of 200 °C under a pressurized water atmosphere of 10 MPa. The corrosion test specimens were maintained up to 65 weeks in the tube shaped reactor. The corrosion damages for carbon steels were investigated at the terms of 20, 35, 50 and 65 weeks. In order to investigate the mechanical properties of carbon steels suffered from cyclic corrosion tests, the tensile test was conducted at the room temperature. The dimensions of tensile test specimen with a gauge length of 25 mm were 100(l)×10(w)×4(t) mm^3. The crosshead speed for tensile tests was fixed as 0.1 mm/min. The weight loss of carbon steels by cyclic corrosion tests was measured to examine the surface damages. The microstructure of carbon steels was observed by an optical microscopy. The X-ray diffraction (XRD) analysis was also carried out to identify phases in the corrosion morphology of carbon steels.

The nondestructive technique for the corrosion damages of carbon steels was conducted to examine the attenuation coefficient of ultrasonic wave by cyclic corrosion tests, using the water-immersion method. The dimension of test sample was 20(w)×25(l)×10(t) mm^3. The frequency range of transmitter used in this test was 10 MHz. The schematic diagram of acoustic emission test for evaluation on microscopic damage behavior of the corroded specimen was also shown in Fig.1. During the tensile test, the sensor attached on the surface of test specimen receives the signals for the deformation of test sample and its crack initiation. The received signals were amplified through the pre-amp (40dB) and analyzed in the main board. The acoustic emission test was conducted with a threshold of 40dB to eliminate the noises, using a sensor wideband of 100kHz – 1200kHz.



(a) High temperature corrosion test device (b) Acoustic emission test

Fig. 1 Schematic diagrams for high temperature corrosion test and acoustic emission test..

Results and discussion

Fig. 2 shows the effect of corrosion cycle period on the weight loss of carbon steels by the pressurized water corrosion test. The XRD analysis for the corrosion surface of carbon steels was shown in this figure. The weight loss of carbon steels slightly increased with the increase of corrosion cycle period, after a rapid increase of weight loss at the corrosion cycle period of 20 weeks. The carbon steel also represented a weight loss of about 2.7 % at the corrosion time of 65 weeks. This is caused by the activation of corrosion damages on the surface of carbon steels. As shown in the results of XRD analysis, the carbon steel showed a different pattern after the corrosion test of 35 weeks. All peaks for as-pressed carbon steels mainly represented the α-Fe phase. On the contrary, some amount of secondary phases like Fe_3O_4 was clearly identified in the test sample, due to the surface corrosion

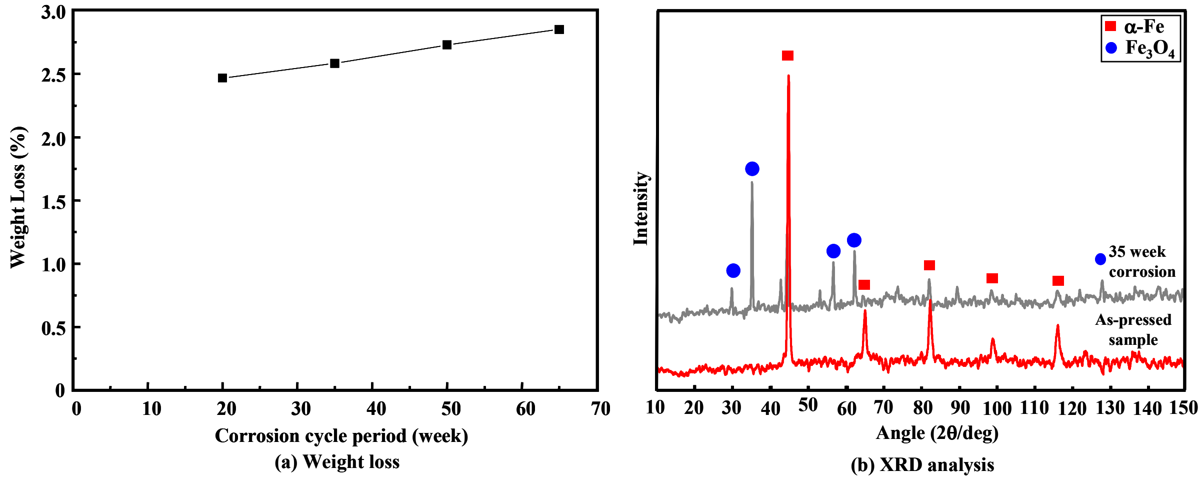


Fig. 2 Weight loss and XRD result of carbon steels eroded at the different corrosion cycle.

by the pressurized water vapors. Such a creation of surface damages such as pore and void on the can be regarded as a factor to increase the weight loss of carbon steels.

Fig. 3 shows the effect of corrosion cycle period on the tensile strength and the attenuation coefficient of carbon steels suffered from the pressurized water corrosion test. The tensile strength of carbon steels was steadily affected by the corrosion cycle period, even if it had a similar strength level up to the corrosion cycle period of 20 weeks. In other words, the carbon steels maintained an average tensile strength of about 500 MPa for the corrosion cycle period of 20 weeks. However, the carbon steels represented the tensile strength of about 380 MPa at the corrosion cycle period of 50 weeks, which corresponds to about 75 % of as-pressed carbon steels. It was also found that the attenuation coefficient of carbon steels was greatly changed by the period of corrosion cycle. The attenuation coefficient of carbon steels greatly increased with the increase of corrosion cycle period. This is maybe caused by both the reflection of ultrasonic wave from the surface of test sample and the partial propagation of wave into the water.

Fig. 4 shows the AE parameter results for the tensile specimen corroded at the corrosion cycle periods of 0 week and 20 weeks. Both the amplitude and the AE energy of tensile specimens did not represented a big difference, regardless of the corrosion cycle. The AE signals (above100) for the specimen without the corrosion did not generate at the beginning of tensile load. On the contrary, lots of AE signals generated in the corroded specimen, due to the creation of corrosion damages. The

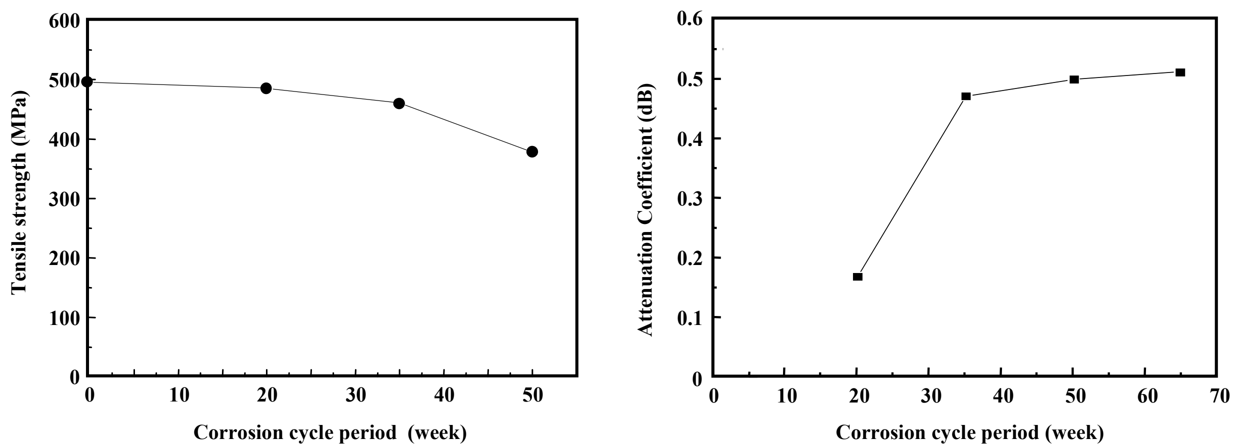
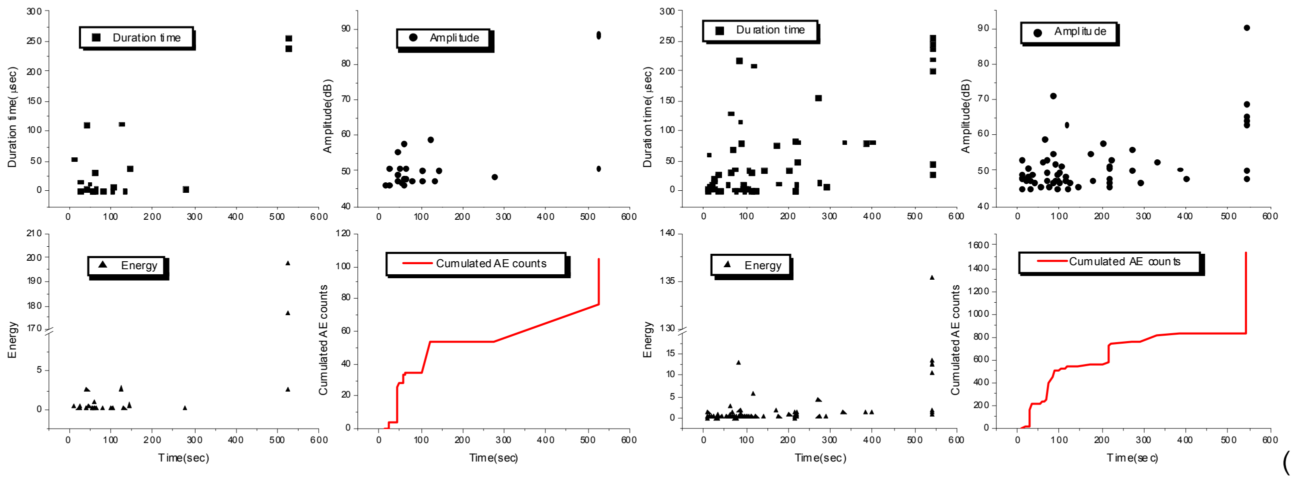


Fig. 3 Effect of corrosion cycle period on the tensile strength and the attenuation coefficient of carbon steels.

cumulated count also showed the exponential growth at the corrosion cycle period of 20 weeks. From these results, it was found that the corrosion damages of the pipeline materials like carbon steel could be evaluated by the analysis of the useful AE parameters.



(a) 0 week (b) 20 weeks

Fig. 4 AE parameter results for the corroded tensile specimen.

Summary

The carbon steels represented a weight loss of about 2.7 % at the corrosion time of 65 weeks, accompanying the creation of some amount of Fe_3O_4 phases on the surface of carbon steels. The tensile strength of carbon steels steadily decreased with the increase of corrosion cycle period. Especially, the carbon steels represented the tensile strength of about 380 MPa at the corrosion cycle period of 50 weeks, due to the activation of corrosion damages. In addition, the attenuation coefficient of carbon steels greatly increased with the increase of corrosion cycle period, since the ultrasonic wave reflected from the surface of test sample and partially propagated into the water. The effective AE signals for the corroded tensile specimen also generated at the corrosion cycle period of 20 weeks, accompanying the exponential growth of cumulated count. The nondestructive technique can be conducted to investigate the detection of damages in the structure of carbon steels.

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