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Mechanical Properties of Thermally Aged Austenitic Stainless Steel Welds and Cast Austenitic Stainless Steel

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1. Introduction

Austenitic stainless steels and associated welds have been widely used for the pressurizer surgeline of pressurized water reactors (PWRs). Such welds typically contain certain amounts of ferrite to prevent hot cracking as well as to achieve higher strength [1]. Also, cast austenitic stainless steels (CASSs) had been used in primary system pipes. However, ferrites in welds and CASSs may cause the degradation of mechanical properties due to thermal aging during the long-term operation [2]. Conventional test methods for tensile and J-R properties of such weld require large size specimens. Meanwhile, small punch (SP) test has advantages of using small size samples at specific location [3]. In this study, the mechanical property changes caused by the thermal aging were evaluated for the stainless steel welds and CASSs using tensile, J-R, and SP test. Based on the results, correlations were developed to estimate the fracture toughness using the load-displacement curve of SP tests. Finally, the fracture surfaces of compact tension (CT) and SP test specimens are compared and discussed in view of the effect of thermal aging on microstructure.

2. Materials and Experiment

2.1 Test Materials

In this study, the mechanical property changes caused by thermal aging were evaluated for the ER316L and ER347 welds as well as CF8M. The filler metal composition was estimated to produce the welds with ferrite contents of approximately 10 vol. %. The chemical compositions and ferrite contents of welds and CF8M blocks are listed in Table I. The welding blocks of ER316L and ER347 were fabricated by using manual gas-tungsten arc welding (GTAW) with build-up welding process. Fig. 1 shows the schematic design of welding block.

Table I: chemical compositions and ferrite contents of test materials

wt. %	Cr	Ni	Mo	C	Si	Mn	Nb	%F
ER 316L	18.4	11.0	2.56	.008	.4	1.74	-	11
ER 347	19.0	9.04	.17	.045	.38	1.53	.69	10
CF8M	20.5	8.19	2.63	.05	.66	.86	-	34

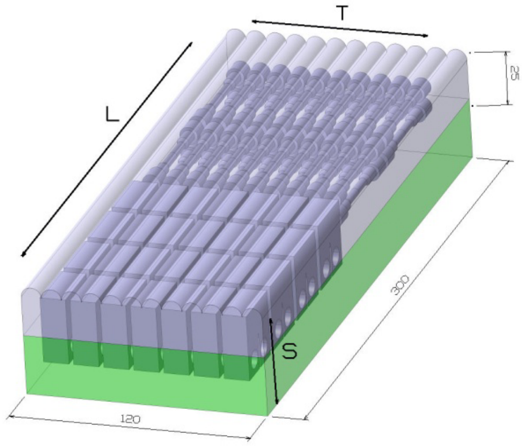

Fig. 1. Schematics of the stainless steel weld

The materials were thermally aged at 400 °C for 5,000 h. The aging temperature (400 °C) represents accelerating condition compared to operating condition (343 °C) of pressurizer surgeline in PWR.

2.2 Mechanical properties test

To investigate the mechanical properties of stainless steel welds and CF8M, tensile, J-R, and SP tests are performed at room temperature and 320 °C in air. Tensile test was performed by using round bar specimens with a strain rate of 5×10^{-4} /s following the procedures of ASTM E8/E8M-13a [4]. The J-R curve was measured using 1/2T-CT specimen by normalization method following the procedures of ASTM E1820-13 [5]. CT specimens were notched so that the crack would propagate in the direction of welding (L-S orientation). The ratio of pre-crack length to specimen width (a/W) was approximately 0.57. The schematic design of SP test is shown in Fig. 2. SP test are in progress at room temperature and 320 °C using sheet type specimen (10 x 10 x 0.5T).

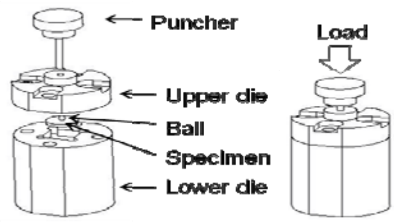

Fig. 2. Schematics of SP test

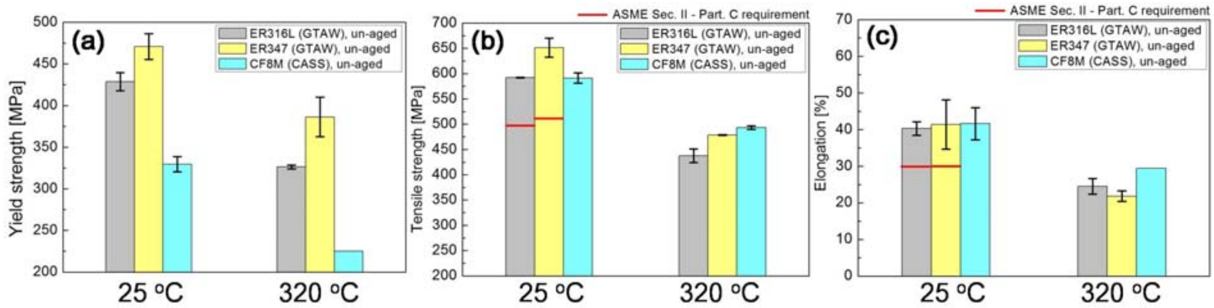

Fig. 3. The result of tensile properties of un-aged specimen: (a) yield strength, (b) tensile strength, and (c) elongation

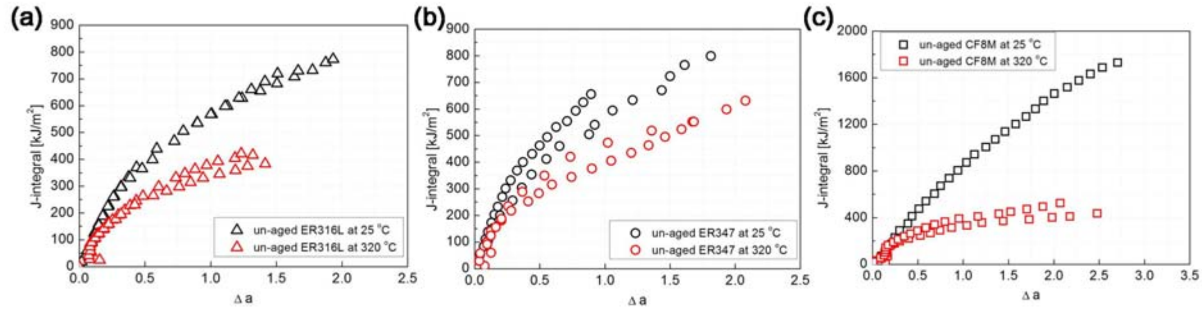

Fig. 4. The result of J-R tests of un-aged specimen: (a) ER316L, (b) ER347, and (c) CF8M

3. Results and Discussion

3.1 Tensile properties

The result of tensile tests for un-aged specimens, tensile properties are shown in Fig. 3. It can be seen that the tensile properties of ER316L and ER347 meet the ASME (sec. II – part. C) requirement. Tensile properties are decreased at 320 ^{o}C. For aged specimens, tensile test are in progress to determine the degradation of test materials by thermal aging.

3.2 Fracture toughness

Fig. 4 shows the result of J-R tests for un-aged specimens. Fracture toughness of all test materials are decreased at 320 ^{o}C compare to room temperature (25 ^{o}C). Similar to tensile test, J-R test of aged specimens are on going to evaluate the effect of thermal aging on welds and CF8M.

4. Summary

Stainless steel welds of ER316L and ER347 as well as CASS (CF8M) were thermally aged at 400 ^{o}C for 5,000 h. So far, tensile properties and fracture toughness of un-aged materials were carried out at room temperature and 320 ^{o}C as a reference data. In order to evaluate the effect of thermal aging on mechanical properties, aged specimens are being tested and the changes in these properties will be discussed. In addition, correlations will be developed to estimate the fracture toughness in between J-R curve and SP curve.

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