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Effects of Thermal Aging on Type 316H Stainless Steel for Reactor Vessel

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1. Introduction

Type 316H stainless steel is a prime candidate for reactor vessel material of sodium-cooled fast reactor (SFR) which has been developed as one of the Gen IV nuclear reactors in Korea. The reactor vessel steel will be exposed to higher temperature for an extended design life time. It is known that austenitic stainless steel such as Type 316H stainless steel shows excellent toughness and adequate strength at a moderate temperature. However, the previous researches reported the mechanical properties of Type 316H stainless weld would be deteriorated by the aging at the elevated temperature range [1-6]. Therefore, the thermal aging effects on Type 316H stainless steel weld were investigated in this study

2. Experimental

2.1 Material and Heat Treatment

Type 316H stainless steel plate of a thickness 19 mm was gas-tungsten arc(GTA) welded with the ER316H welding rods. The chemistries of a plate and filler material are listed in Table 1.

(wt%)	C	Si	Mn	Cr	Ni	Mo	Cu
Base Plate	0.04	0.41	1.78	16.36	10.06	2.02	0.37
Filler	0.04	0.47	1.60	19.08	12.03	2.13	0.24

Fig. 1 shows the welded Type 316H stainless steel test blocks.

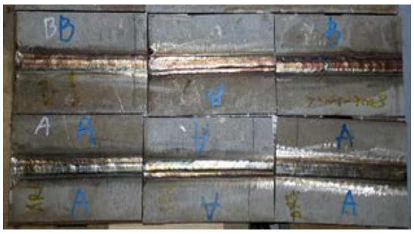

Fig. 1. GTA welded Type 316H stainless steel test blocks.

Type 316H stainless steel welds were aged at 800K and 900K for 2,500 hrs in an electric furnace. The aging temperatures were selected considering the spinodal decomposition and phase transformation of delta ferrite in a Type 316H weld.

2.2 Microstructural Analyses

The delta-ferrite contents in pre-aged and post-aged welds are measured by using a ferrite scope. The microstructural analyses were conducted by using optical microscope, FE-TEM, SEM-EDS.

2.3 Mechanical Testing

The subsized tensile specimens were fabricated from Type 316H plate and GTA welds before and after thermal aging. The tests were conducted by using a servo-hydraulic test machine. The temperatures were 390°C and 500°C.

3. Results

3.1 Calculation of Phase Diagram

The equilibrium phase diagram in Type 316H stainless steel was constructed by using Thermo Calc. As shown in Fig. 2, The sigma phase is stable at 400-700°C. The Cr-rich phase is stable at about 420°C.

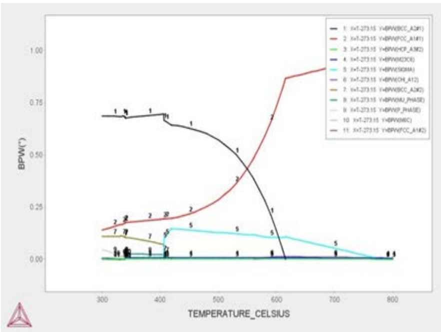

Fig. 2 Phase diagram for Type 316H stainless steel.

3.2 Microstructure

The as-received Type 316H stainless steel weld contained δ-ferrites of 8-10% as dendrite forms. The content of δ-ferrite decreased to 5-6% after the thermal aging at 800K for 2,500 hrs. The spinodal decomposition of δ-ferrite occurred and austenite and $M_{23}C_6$ precipitates were formed in δ-ferrite as shown in Fig. 3. The sigma phase also formed at δ-ferrite/austenite interface. After the thermal-aging at

900K, All δ-ferrites were transformed to austenite and coarse $M_{23}C_6$ as shown in Fig 4.

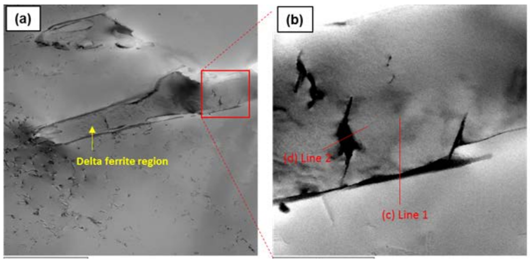

Fig. 3. TEM images of weldment after heat treatment at 800K for 2,500hrs; (a) low magnification TEM image, (b) high magnification TEM image.

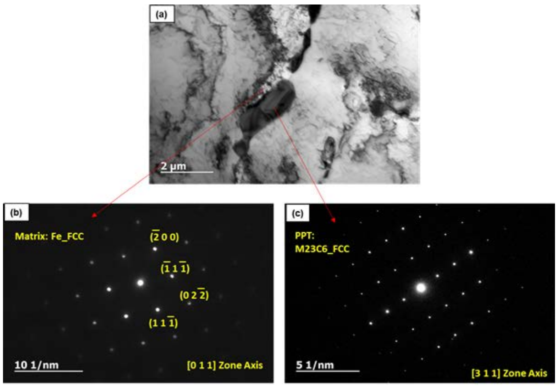

Fig. 4. TEM image and diffraction pattern analysis results of weldment after heat treatment at 900K for 2,500hrs; (a) TEM image, (b) diffraction pattern of matrix, and (c) diffraction pattern of precipitate.

3.2 Mechanical Properties

The effects of thermal aging on mechanical properties of base materials were not clear. However, in case of weldment, the elongation of specimens tested at high temperature (390°C and 500°C) were reduced by more than 30%, and the reduction was larger at 500°C. The amount of reduction in elongation did not different with thermal aging temperature, but yield strength of weldment aged at 627°C were largely decreased as summarized in Table 2.

Table 2. . Comparison of tensile properties of pre-aged and post-aged Type 316H stainless steel plate.

Test Temp.	Aging Temp.(K)	Y.S. (MPa)	U.T.S. (MPa)	U.E. (%)	T.E (%)
390°C	-	287	444	22	31
	800	283	414	14	20
	900	210	439	16	22
500°C	-	258	258	23	34
	800	281	388	13	19
	900	210	417	14	18

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