Transactions of the Korean Nuclear Society Autumn Meeting
Busan, Korea, October 27-28, 2005

Mechanical Property Changes during Accelerated Thermal Aging Embrittlement Heat Treatment of Cast Stainless Steel, CF-8A

KhingMay Wann, Joo Suk Lee, and Changheui Jang*
Department of Nuclear and Quantum Engineering, KAIST, 373-1, Guseong-dong, Yuseong-gu, Daejeon 305-701, Korea, chjang@kaist.ac.kr

1. Introduction

Cast stainless steels are widely used in the primary coolant piping of pressurized water reactors (PWRs). This cast stainless steel contains a ferrite phase of about 10~25% in an austenite matrix. These materials suffer thermal aging embrittlement when exposed to the operating temperature of nuclear power reactor over a long period. The results of the embrittlement are loss of ductility and fracture toughness while the strength is increased.

To assure the integrity of the components fabricated of cast duplex stainless steels for their lifetime or an extended lifetime, it is very important to evaluate the degree of thermal aging embrittlement[1]. It is common that the specimens are aged at higher temperature than the normal operating temperature to accelerate the thermal aging embrittlement phenomena.

The purpose of this study is to provide the information on the changes of the mechanical properties of cast stainless steels during the accelerated testing. The changes in microhardness are measured and the changes in tensile properties at room temperature.

2. Experimental

An experimental heat of cast stainless steel (CF8A), whose composition is shown in Table 1 was used in the study. The ferrite content of the specimen was calculated as about 20%. The specimens were exposed at 400℃ for prolonged time in the laboratory furnace to accelerate the thermal aging embrittlement phenomena in plant service environment. The accelerated aging conditions are approximately equivalent to 30, 40, and 60 years of operation at 320℃. The materials heat was originally produced to be used in. The specimens used in this study were taken from the broken pieces of fracture toughness test specimens which were conducted as part of environmental fatigue evaluation of cast stainless steels[2].

Table 1. Chemical composition of test specimen

element	C	Mn	Si	Cr	Ni	Mo	S	P	Co
wt.%	0.045	0.60	1.17	20.08	8.38	-	0.018	0.024	0.10

Microhardness measurements and tensile test were carried out. For microhardness measurements, each specimen was mechanically polished with diamond paste up to 6 μm and was etched in a solution of 50 g NaOH in 100 ml water at 2 V for 5 seconds to distinguish between ferrite and austenite phases. Ten measurements were made for each sample and for austenite and ferrite grains, respectively and the results were averaged.

Tensile tests were conducted at room temperature. To confirm these test results we have planned to perform tensile test at the high temperature of 320ºC, the operation temperature of nuclear power plant.

3. Result and Analysis

3.1 Microhardness test results and analysis

The microhardness values of ferrite and austenite phases of all specimens are listed in Table 2. The data show that there is no change in the microhardness of austenite phase with aging time, having a little scattering. On the other hand, as can be clearly seen in this table, the microhardness of ferrite phase was found to increase with aging time. This result indicates that the embrittlement phenomenon is accompanied by an increase in hardness[3,4,5]. On the other hand, the optical micrographs did not show any clear changes in microstructures during the accelerated aging of the materials.

Table 2. Change of microhardness of ferrite and austenite phases during accelerated aging

Specimens	Ferrite phase	Austenite phase
As received	234.9	195.9
J5 (400C+3943 hr)	280.3	210.2
J8 (400C+5270 hr)	334.5	192.5
J10 (400C+8000 hr)	360.3	201.8

3.2 Tensile test results and analysis

The changes of tensile properties during the accelerated aging are shown in Table 3. Yield strength increased with aging time up to 30 years, and it decreased on further aging for 40 years. But it increased again for 60 years aged materials. An identical trend was seen for the variation of UTS with aging time also. Contrary to current study, decrease of strength in CF-8A with similar composition was reported in both room temperature and operating temperature after accelerated aging[6]. In that study, decrease in Brinell hardness was also observed. On the other hand, similar variations of tensile strength and UTS have been reported in other studies[7]. Total elongation also changed as the accelerated aging progresses but at less degree.

To confirm the results of room temperature tensile test, we will perform high temperature test and the results will be shown later.

Table 3. Tensile test results at room temperature

Aging Time	Specimens	Yield Strength (MPa)	Ultimate Strength (MPa)	Total Elongation (%)
As-received	as-0.227-rt	349.11	437.52	23.7
	as-0.226-rt	373.52	459.78	49
	as-0.237-rt	373.67	471.81	27.2
	average	**365.43**	**456.36**	**33.3**
30 years (400C+3943 hr)	j5-0.233-rt	404.76	612.04	34.1
	j5-0.240-rt	414.37	566.92	47
	j5-0.244-rt	412.77	578.8	37.8
	average	**410.63**	**585.92**	**39.6**
40 years (400C+5270 hr)	j8-0.237-rt	331.07	468.16	31.7
	j8-0.232-rt	351.75	539.44	52.7
	j8-0.233-rt	297.67	414.12	24.4
	average	**326.83**	**473.90**	**36.3**
60 years (400C+8000 hr)	j10-0.226-rt	370.41	532.64	40.57
	j10-0.231-rt	360.03	497.8	39.4
	j10-0.246-rt	391.35	588.46	39.4
	average	**373.93**	**539.63**	**39.8**

3.3 Microstructure

The typical optical microstructures of the specimens are shown in Figure 1. No significant changes in microstructural features are observed. There was a report that the loss of strength in aged specimens was related to the segregation of Cr to ferrite/austenite boundary and precipitation of chromium carbide[6]. However, no carbide-like precipitates were observed in SEM micrographs of the tested specimens. It is planned to compare the variation of chemistry along the ferrite and austenite phases using EDS.

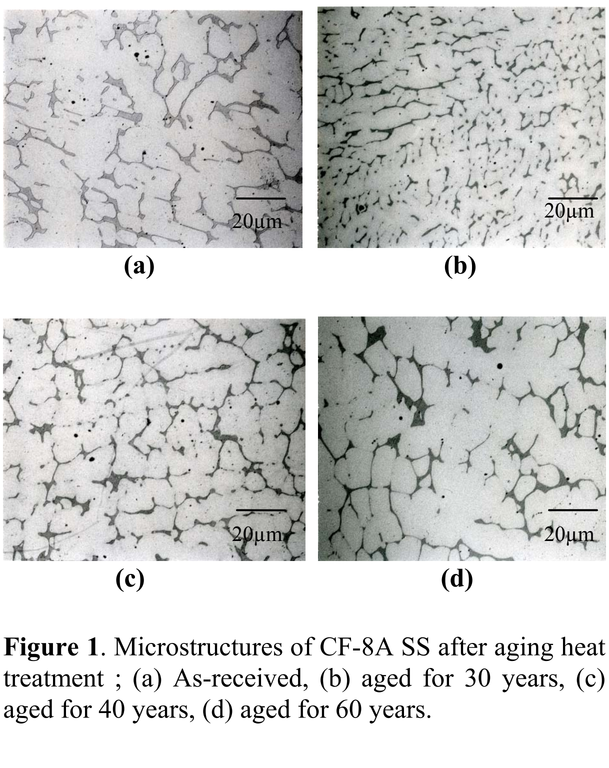

Figure 1. Microstructures of CF-8A SS after aging heat treatment ; (a) As-received, (b) aged for 30 years, (c) aged for 40 years, (d) aged for 60 years.

4. Conclusions

Microhardness and tensile tests have been carried out on CF8A SS after accelerated thermal aging at 400 ºC for prolonged time to simulated the 30, 40, and 60 years of operation in nuclear power plant.

- The microhardness of ferrite phase was found to increase with aging time while there is no change in the austenite phase.
- Yield strength at room temperature increased with aging time up to 30 years, and it decreased on further aging for 40 years. But it increased again for 60 years aged materials.
- The reason of tensile property variation with aging time is not clear, and detailed analyses on chemistry variation and precipitation are needed.

REFERENCES

[1] V. N. Shah and P. E. Macdonald, Aging and Life Extension of Major Light Water Reactor Components, 1993.
[2] T. H. Song, et al., Environmental fatigue crack growth rate characteristics of austenitic stainless steel CF8M and CF8A in PWR conditions, presented at ICAPP 2005, Seoul, Korea, May 15-19, 2005.
[3] K. L. Weng, et al., The high temperature and low temperature aging embrittlement in A2205 duplex stainless steel, Bulletin of the College Engineering, N.T.U., No.89, pp.45-61, 2003.
[4] Y. S. Yi and T. Shoji, Detection and evaluation of material degradation of thermally aged duplex stainless steels: electrochemical polarization test and AFM surface analysis, Journal of Nuclear Materials, Vol. 231, pp.20-28, 1996.
[5] J. S. Park and Y. K. Yoon, Evaluation of thermal aging embrittlement of duplex stainless steels by electrochemical method, Scripta Metallurgica et Materialia, vol.32, No.8, pp.1163-1168, 1995.
[6] S. Baek, et al., Evaluation of the degradation characteristics of CF-8A stainless steel using ABI and EDS, presented at 2004 KSME Meeting on Materials and Fracture, Daejeon, Korea, Aug. 20, 2004.
[7] M. D. Mathew, et al., Low temperature aging embrittlement of CF-8 stainless steel, Material science and engineering A, Vol.269, pp.186-196, 1999.