EFFECTS OF THERMAL AGING ON THE VARIOUS MECHANICAL PROPERTIES OF CF8A

*Taek-Ho Song, Ill-Seok Jeong, Sung-Yull Hong, Sang-Jai Kim
Korea Electric Power Research Institute
103-16, Munji-dong, Yousung-Gu, Daejon City
Tel:042-865-5515 , Fax:042-865-5604 , Email: thsong@kepri.re.kr

1. Introduction

Cast austenitic stainless steel CF8A, has been used for 21 years in Kori Unit 2 reactor coolant piping. CF8A materials is being used in other nuclear power plants such as Kori unit 3,4 and Youngkwang unit 1&2.

Periodic Safety Review(PSR) has been carried out for the Kori Unit 1 and 2, For the Kori Unit 3 and 4, it is still going on. In PSR, aging is one of the safety parameters which International Atomic Energy Agency(IAEA) has defined.

As far as aging of nuclear power plant piping material is concerned, thermal aging is the most important factor that affects the life of reactor coolant piping, just as irradiation embrittlement is the most significant one that has an impact on the life of reactor pressure vessel[1-3].

This paper describes experimental and analysis results of the tensile, fracture, and fatigue tests which were performed at the reactor operation temperature of 320℃, to describe the effects of thermal aging on the various mechanical properties of CF8A. The purpose of this study is to provide basic data for the PSR evaluation of piping aging.

2. Experiment

Test specimen blocks are manufactured according to certified material test report(CMTR) of piping of Kori and Youngkwang NPP. It will be the best policy to test the real material used in NPP, however it was turned out that there are no available test materials from the manufacturer. So we had no choice and made test specimen by using CMTR. Test specimen block was produced at FOSCO and Samshine Steel companies. Detailed chemical content of each test specimen is shown in Table 1.

Test specimen for the J-R test and fatigue was manufactured in the shape of 1TCT according to ASTM procedure. And Test specimen for the tensile test was manufactured in the shape of dog bone shape according to ASTM procedure[1] All the tests were performed at the high temperature of of 320℃ which is the operation temperature of the nuclear power plant.

Table 1. Chemical compositions of CF8A Test Specimen

Wt %	C	Mn	Si	Cr	Ni	Mo	S	P	Co
CF8A	0.05	0.6	1.2	20.5	8.5	-	0.02	0.03	0.1

Aged test specimens have been prepared for the simulation of 60 year operation in NPP. This simulation was done by Arrenius experimental equation. For the Arrenius simulation, we used the following values of the aging parameters.

Q= 125 kJ/mole,
Operating temperature = 320 ℃
Aging temperature = 400 ℃

Table 2. High temperature Tensile Test Results

Aging Time (Years)	Specimen	0.2% Offset Yield Strength (MPa)	Ultimate Strength (MPa)	Total Elongation (%)
0.0	CF8A4	220.6	512.4	35.3
	CF8A5	255.6	490.1	25.6
	CF8A6	209.0	469.8	41.6
	average	228.4	490.8	34.2
60.0	CF8A7	222.0	599.1	22.0
	CF8A8	212.0	575.0	26.0
	CF8A9	222.5	605.7	26.4
	average	218.8	593.3	24.8
Tensile Property Change(%)		-4.2	20.9	-27.4

3. Test Results and Analysis

3.1 Tensile Test Results and Analysis

As shown in Table 2, tensile properties of piping change as the nuclear power plant ages. Yield Strength, however, changed very little. Ultimate tensile strength increased by 20.9 %, while total elongation decreased by 27.4%, which means that toughness has decreased by thermal aging effect.

3.2 Fracture Test Results and Analysis

Table 3. High temperature J-R Test Results

Aging Time (Years)	Specimen	J_{IC} (kJ/m^2)	C_1 (kJ/m^2)	C_2
0	CF8AJ1	441.2	499.9	0.606
	CF8AJ2	605.1	592.4	0.5
	CF8AJ3	622.6	602	0.529
	average	556.3	564.76667	0.545
60	CF8AJ4	553	577.2	0.332
	CF8AJ5	416.2	502.5	0.554
	average	484.6	539.85	0.443

As shown in Table 3, critical J value(fracture toughness) of piping material decreased by 12.9% as the nuclear power plant ages, and this means that the resistance to crack initiation and propagation of the material decreases by 12.9% as the power plant ages by thermal aging effect[4].

When we apply this aging effect to the equation for thermal aging estimation which Choppra sugested[5-7], it becomes the following as in Table 4.

Table 4. Chopra equation analysis result.

Cr_eq	Ni_eq	delta ferrite (Dc)	Material Para. P	Cv_sat1	Cv_sat2	Cv_sat lower
16.09	12.56	20.11	21.82	60.77	56.24	56.24

Table 5. J_{IC} estimation by using Choppra equation

J_{IC}	C_v	Δa	n	Years	temp.
363.84	146.7	0.2	0.4599	0	320
267.79	72.65	0.2	0.4233	60	320

When we compare the J_{IC} value in Table 5 to that in Table 3, the J_{IC} amount of value in Table 5 is less than that in Table 3, however, as the nuclear power plant ages, the amount of decrease in J_{IC} is 26.4% which is more than that in Table 3.

3.3 Fatigue Test Results and Analysis

In table 6, Paris Equation Constants[8] of C and m are shown. When the plant ages, the exponential index m increased which means that thermal aging certainly affected the rate of fatigue propagation of nuclear piping material in a certain amount.

Table 6. Fatigue Test Results

Aging Time (Years)	Specimen	C	m
0	CF8AF1	3.00E-12	5.07
0	CF8AF2	3.00E-13	5.70
60	CF8AF3	1.00E-14	7.86

4. Conclusion

This paper described experimental and analysis results of the tensile, fracture, and fatigue tests which were performed at the reactor operation temperature of 320℃. Yield Strength changed very little by thermal aging. Ultimate tensile strength increased by 20.9 %, while total elongation decreased by 27.4%, which means that toughness has decreased by thermal aging effect. It turned out to be that critical J value(fracture toughness) of piping material decreased by 12.9%, and fatigue propagation rate increased as the nuclear power plant ages.

These test results are expected to be used for the PSR evaluation of piping aging of nuclear power plants.

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