Stress Corrosion Cracking of FM Steels in Supercritical Water

Seong Sik HWANG[1], Byung Hak LEE[1], Jung-Gu KIM[2], Jinsung JANG[1]
[1]:*Korea Atomic Energy Research Institute, 150 Deokjin-dong, Yuseong-gu, Daejeon, Korea*
sshwang@kaeri.re.kr
[2] : *Department of Advanced Materials Engineering, SungKyunKwan University*
300 Chunchun-Dong, Jangan-Gu, Suwon 440-746, Korea

1. INTRODUCTION

As one of the Generation IV nuclear reactors, Supercritical Water Cooled Reactor (SCWR) is considered as a candidate reactor due to its high thermal efficiency [1,2]. At above the supercritical condition of 374 °C, 22.1 MPa, the supercritical water does not change the phase through the reactor core outlet. Then the high temperature coolant is effectively used at on over 40 % thermal efficiency. A critical step for this good feature to be attainable is to choose the proper structural materials. For an application of the structural materials to a core internal, fuel cladding, the materials should be evaluated in terms of their high temperature tensile strength, creep strength, corrosion and stress corrosion cracking susceptibility, radiation resistance, weldability, etc. Among the qualification items, stress corrosion cracking (SCC) tests of F/M steels have been performed in supercritical water environment.

This work aims at evaluating stress corrosion cracking behavior of F/M steels as candidate materials for the SCWR.

2. EXPERIMENTAL

Two feritic-martensitic(F/M) steels ((T 91-I, T 92) were tested in a supercritical water environment. Table 1 shows the chemical compositions of the test materials. Deionized water (~0.05 uS/cm) of below 10 ppb of dissolved oxygen and about a pH of 6.5 was used as a test solution. SCC tests using a slow strain rate tester (SSRT) and U-bend specimens were carried out at 500, 550, and 600 °C. The surface of the U-bend specimens was polished with up to 0.3 micrometer alumina powder before the U shape bending. The SSRT specimens were ground with #600 SiC emery paper on the gauge section followed by a cleaning with acetone. The SCC test using the U-bend and the SSRT was carried out simultaneously in the same autoclave. After the tests, a gage section of the SSRT specimens were observed with a Scanning Electron Microscope (SEM) to confirm a SCC. The cross sections of the U bend specimens were analyzed with the SEM.

The corrosion and SCC test loop of a supercritical water environment designed for a 650 °C, 30 MPa operation is shown in Fig. 1. It consists of a pressure vessel of a 3.3 liter volume capacity made of Hastelloy C-276, a make up water control loop, a SSRT control unit, data acquisition module etc.

3. RESULTS and DISCUSSION

3.1 Test Temperature Dependence

T 91 steels did not show a SCC in the SSRT test at 550, and 600 °C, but they exhibited an oxide film rupture at the necking area as shown in Fig. 2. The specimens failed in a ductile fracture mode at 500 °C. As the test temperature increased, ultimate tensile strengths (UTS) and yield strengths (YS) of the T 91 alloy were decreased as shown in Fig. 3.

Strain rates at 500 °C and 550 °C were $1.5*10^{-7}$/sec and $3.0*10^{-7}$/sec respectively. It has been reported that the maximum stress is increased as the strain rate is increased for alloy 600 in a high temperature water [3]. In this test,

Table 1. Chemical compositions (wt%) of the tested alloys

Alloy	Fe	C	Si	Mn	P	S	Cr	Ni	Mo	–
	-	V	Nb	W	Ti	Al	N	O	Cu	others
T91- I	Bal	0.084	0.438	0.363	0.019	0.0008	8.876	0.102	0.928	–
	-	0.197	0.081			0.016	0.0351		0.081	
T92	Bal	0.07		0.45			9		0.5	–
	-	0.2	0.05	1.8			0.06			

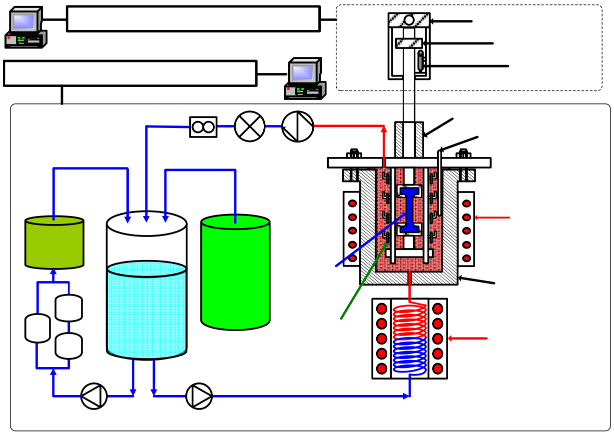

Fig. 1 Corrosion and SCC test loop of the supercritical water environment

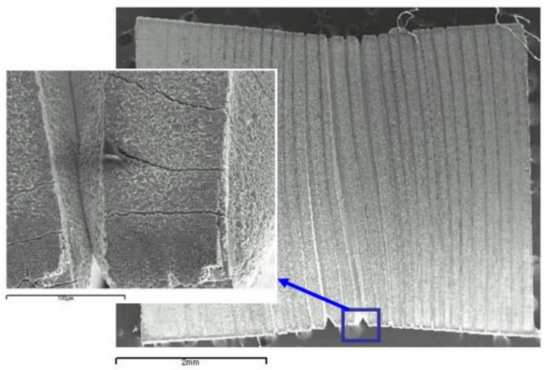

Fig. 2 Feature of necking of T 91-I tested at 500°C using SSRT

Alloy T 91 tested at showed lower UTS at a fast straining of $3.0*10^{-7}$/sec than at a slow straining of $1.5*10^{-7}$/sec. The low UTS at the fast strain rate of Alloy T 91 seems to be from the high test temperature of 550 °C; an increase of the strain rate did not facilitate an increase of the UTS. Compared with the UTS at 550 °C, the low UTS at 600 °C explains the dominant effect of test temperature on the tensile properties. The elongations were similar (about 20%) regardless of the test temperatures.

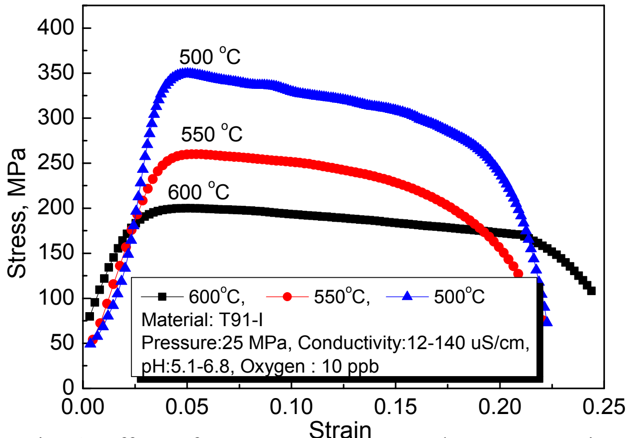

Fig. 3 Effect of test temperature on the stress strain curves of the alloy T 91-1 in supercritical water.

3.2 Effect of dissolved oxygen

Alloy 91-1 tested in 100 ppb dissolved oxygen(DO) content showed a little lower UTS than in 10 ppb DO as shown in Fig. 4.

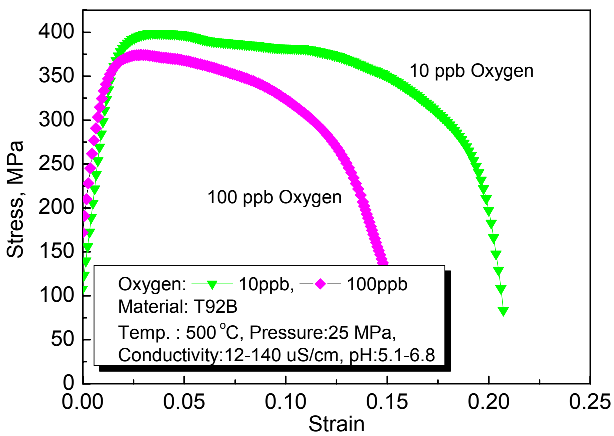

Fig. 4 Effect of dissolved oxygen on the stress strain curves of alloy 91-1 in SCW.

An elongation, however, decreased a lot as the DO increased. This implies that high DO caused a high oxidation reaction on the surface of the test specimen, the a low ductility of the material.

3.3 Material dependence

Fig. 5 shows the material dependency on the tensile strength of the FM steels in SCW. Alloy T 92B showed a higher UTS than that of T 91 at 500 °C at the same strain rate of $1.5*10^{-7}$ /sec; 399 MPa for T 92, 349 MPa for T 91. It is believed that W and N of alloy 92B increased the UTS. It seems to be necessary to do a systematical test to ensure the effect of the minor elements.

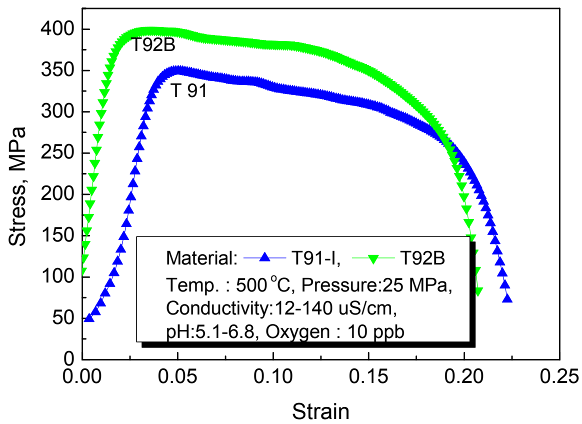

Fig. 5 Material dependence on the stress strain curves of the FM steels in SCW.

U-bend specimens of T 91 did not show any cracking at the apex of the U-bend regardless of the test temperature at 500 °C and 550 °C.

4. CONCLUSIONS

-No SCC was observed on the fracture surface of T 91 steel in the supercritical water at 500 °C, 550 °C and 600 °C.
-As test temperature increased, UTS and YS of T 91 decreased.
-High dissolved oxygen induced corrosion and low ductility.
-Alloy 92B showed higher UTS than that of alloy 91-1.

ACKNOWLEDGEMENT

The research was sponsored by the Ministry of Science and Technology, Korea under the "National Mid and Long-term Atomic Energy R&D Program. The authors acknowledge Doosan Heavy Insdustry, Korea for providing of sample materials.

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