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Effects of Test Temperature on the Reciprocating Wear of Steam Generator Tubes

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Steam generators (S/G) of pressurized water reactors are large heat exchangers that use the heat from the primary reactor coolant to make steam in the secondary side for driving turbine generators.
Reciprocating sliding wear experiments have been performed to examine the wear properties of Incoloy 800 and Inconel 690 steam generator tubes in high temperature water. In present study, the test rig was designed to examine the reciprocating and rolling wear properties in high temperature (room temperature - 300°C) water. The test was performed at constant applied load and sliding distance to investigate the effect of test temperature on wear properties of steam generator tube materials. To investigate the wear mechanism of material, the worn surfaces were observed using scanning electron microscopy.

At 290°C, wear rate of Inconel 690 was higher than that of Incoloy 800. It was assumed to be resulted from the oxide layer property difference due to the alloy composition difference. Between 25 and 150°C the wear loss increased with increasing temperature. Beyond 150°C, the wear loss decreased with increasing temperature. The wear loss change with temperature were due to the formation of wear protective oxide layer. From the worn surface observation, texture patterns and wear particle layers were found. As test temperature increased, the proportion of particle layer increased.

Keywords : Steam Generator, Inconel 690, Reciprocating Wear, High Temperature

1. INTRODUCTION

Fretting wear damage of steam generator tube is one of the most severe degradation mechanisms in nuclear power plant. Flow induced vibration occurs due to high flow rates and small clearance between tubes and their supports. It is very hard to remove the tube vibrations. Therefore, many wear damages have been reported in SG of nuclear power plants.
Fretting wear in steam generators is affected by parameters governed by fluid flow, e.g., type of tube motion, vibration frequency and impact force at the supports; and also governed by mechanical design, e.g., tube/supports clearance, tube/supports contacting area, material combinations and system operating temperature [1]. Most metals are thermodynamically unstable and react with oxygen to form an oxide [2]. According to Stott and Jiang, the oxide layers may be formed by oxidation of the metal asperities or by compaction of oxidized metallic debris. Oxides properties such as formation rate, strength and composition, are changed with test temperatures. So, it is very important to investigate the effects of environment on wear of SG tubes. In this study, effects of temperature on the steam generator tube wear were investigated.

2. EXPERIMENTAL PROCEDURES

2.1 Materials Preparation

Specimens of tubes 19.05mm diameter by 30mm long, were cut from the as received shape without additional treatments. Chemical compositions are listed in table 1 and 2.

2.2 Test Rig and Experimental Variables

Wear tests of Inconel 690 were performed at various temperatures (25°C, 150°C, 250°C and 290°C) in air and water conditions. Incoloy 800 tubes were tested at fixed temperature (290°C) under the water environment. Water used in experiments was chemically pure without chemical addition. Testing frequency was 10 Hz and displacement was 1,200μm. The test load was 10N. Tests were performed more than 3 times at each experimental condition.

2.3 Worn Surface Observation

To compare wear mechanisms between the test conditions, worn surface was examined using SEM after wear testing.

2.4 Application to Work-rate Model

The work rate model has been widely used to evaluate and estimate wear damage in SG tubes. From the results of wear testing, the wear coefficients of work rate model were calculated.

3. RESULTS AND DISCUSSIONS

3.1 Wear Coefficient in High temperature

Fig. 1 shows the wear rate at elevated temperature (290°C, near the steam generator operating temperature) of Incoloy 800 and Inconel 690 steam generator materials. The wear rate of Inconel 690 was 4 times faster than that of Inocoly 800 material. At high temperature, it seemed that wear rate difference between Inconel 690 and Incoloy 800 was due to the oxide layer and mechanical property differences.

3.2 Effect of Temperature

To investigate the effects of temperature on the wear of Inconel 690 steam generator tube material, tests were performed at various temperature ranges (25°C, 150°C, 250°C and 290°C).
Fig. 2 shows that the change of wear loss according to the test temperatures in water environment. In Fig. 2(a) and (b), the wear loss increases at temperatures between 25 and 150°C and then it decreases at temperatures between 150 and 290°C. The maximum wear loss was observed at 150°C.

3.3 Worn Surface Observation

The texture patterns by abrasive wear were observed at lower temperature range. Severe texture patterns were observed on the surface of 150°C specimen. As test temperature increased, the proportion that covered with particle layers increased and texture patterns disappeared. In worn surface of specimen at 250 and 290°C, most areas covered with particle layer and the fractured particle layers were observed.

4. CONCLUSIONS

At 290°C, wear rate of Inconel 690 was higher than that of Incoloy 800. This was resulted from the oxide layer difference due to the alloy composition difference. In this test, between 25 and 150°C the wear loss increased with increasing temperature. Beyond 150°C, the wear loss decreased with increasing temperature. The wear loss change with temperature was due to the formation of protective oxide layer.

REFERENCES

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Table 1 Chemical composition of Inconel 690 (wt%)

Al	B	C	Co	Cr	Cu	Fe	Mn	Mo	N	Ni	Nb	P	S	Si	Ti
0.50	0.007	0.02	0.02	30	0.5	9	0.5	0.2	0.05	bal.	0.1	0.15	0.01	0.5	0.5

Table 2 Chemical composition of Incoloy 800 (wt%)

Al	C	Co	Cr	Cu	Fe	Mn	N	Ni	P	S	Si	Ti
0.3	0.015	0.1	22	0.75	bal.	0.25	0.03	34	0.2	0.02	0.5	0.5

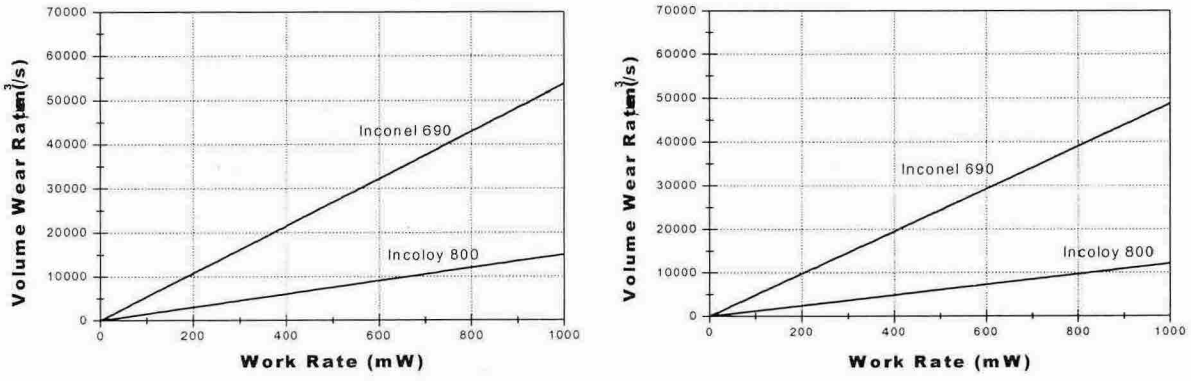

Fig. 1 Results of wear test in 290°C water; using work rate model, (a) loading specimen, (b) sliding specimen

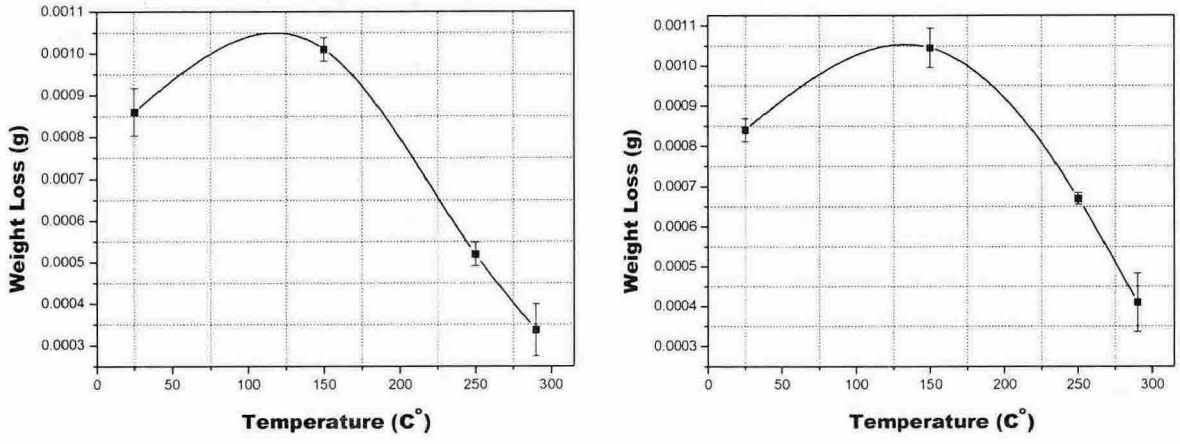

Fig. 2 Effects of temperature on the weight losses of Inconel 690 in water environment
(a) loading specimen, (b) sliding specimen