Out-of Pile Mechanical Test
Simulating Reactivity Initiated Accident (RIA) of Zircaloy-4 Cladding Tube
-Effect of Oxide

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1. Introduction

The ejection or drop of a control rod in a reactivity initiated accident (RIA) causes a sudden increase in reactor power and in turn deposits a large amount of energy into the fuel [1]. In a RIA, cladding tubes bear thermal expansion due to sudden reactivity and may fail from the resulting mechanical damage. Thus, RIA can be one of the safety margin reducers because the oxide on the tubes makes their thickness to support the load less as well as hydrides from the corrosion reduce the ductility of the tubes. In a RIA, the peak of reactor power from reactivity change is about 0.1m second and the temperature of the cladding tubes increases up to 1000℃ in several seconds[2]. Although it is hard to fully simulate the situation, several attempts to measure the change of mechanical properties under a RIA situation has done using a reduction coil [3], ring tension tests with high speed [4,5].

This research was done to see the effect of oxide on the change of circumferential strength and ductility of Zircaloy-4 tubes in a RIA. The ring stretch tensile tests were performed with the strain rate of 1/sec and 0.01/s to simulate a transient of the cladding tube under a RIA. Since the test results of the ring tensile test are very sensitive to the lubricant [4], the tests were also carried out to select a suitable lubricant before the test of oxided specimens.

2. Methods and Results

The test specimens were cut from Zircaloy-4(Zr-1.3Sn-0.2Fe-0.1Cr) tube (out diameter 9.50mm, interior diameter 8.36mm). They were machined with the dimension of 4.27mm in width of the ring, 1.70 mm in reduced width and 2.11 mm in the length of gage section. Expecting mean oxide thickness at different burp-up, the 20, 50, 100μm oxides in thickness of the specimens were made by oxidization at 470℃ in the furnace with the different exposed time. To accelerate the oxidation without the change of mechanical properties, the specimens were oxided at 470℃. The tensile tests of the specimens had been done at room temperature with the strain rate of 1/s and 0.01/s. DSF 3000 lubricant was used for the tensile test of the oxided ring specimens because the test is also to be done at 320℃ in the future to extend this research.

2.1Effect of Lubricant

To select a suitable lubricant, both Molycote and DSF 3000 lubricants were used in the tests because they can be used without the change of their lubrication characteristics at high temperature until 500℃ according to the manufacturer specification. There was less difference in the maximum load and strain of the specimens when they tested with 1/s at room temperature with the DSF 3000 lubricant than with Molycote or without lubricant. As in Fig. 1, the same result was obtained when the tests were done at 320℃ around which the cladding tubes are being used. Therefore, DSF 3000 lubricant was used when the oxided specimens were tested.

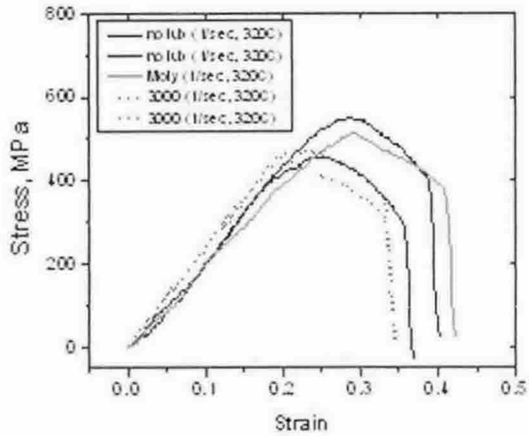

Fig. 1. Lubricant effect on the stress and strain

2.2 Effect of Oxide on the circumferential Strength and Displacement

The maximum oxide thickness of fuel rod at the same burn-up is different from depending on fuel enrichment, operating reactor and cycle. That in mean value of Zircaloy-4 is about 20μm at 20~30GWd/tU, about 50μm at 40~50GWd/tU, and about 100μm at around 60GWd/tU [6]. So, ring tensile tests were done to see the change of the circumferential strength with displacement of Zircaloy-4 when it had 20, 50, and 100 μm in oxide thickness considering a RIA as well as oxide formation, which could be from different burn-up.

Fig. 2 shows the change of strength and the displacement of the specimens with increasing oxide thickness. Both ultimate tensile strength (UTS) and displacement of oxide specimens decrease with thicker in the oxide thickness. Therefore, it seems that the circumferential strength and ductility of Zircaloy-4 cladding tube decreases with increasing burn-up.

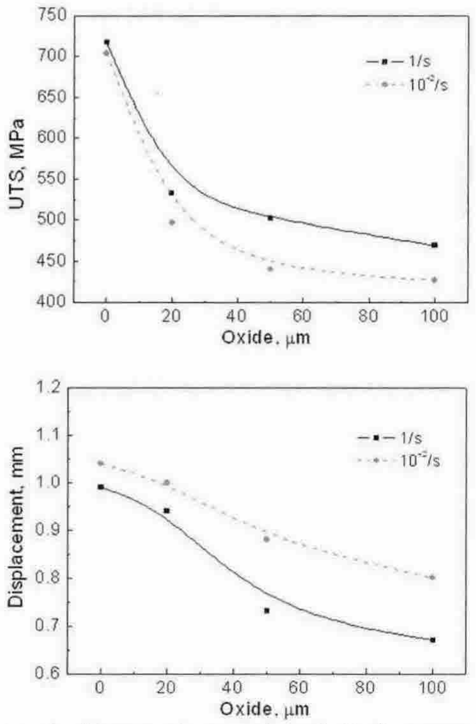

Fig. 2. Change of strength and displacement of ring specimens with different oxide thickness.

Table 1 shows that the change of strength (UTS) and ductility (displacement) of the ring specimens with different oxide thickness from those of non-oxided ones. As in the Table 1, the strength and ductility of ring specimens decreased with increasing the oxide thickness at the circumferential deformation comparing to those of non-oxided ones.

Table 1. Decrease of strength and ductility of ring specimens with different oxide thickness from those of non-oxided ones

Oxide thicknes s (mm)	Change of strength and ductility			
	at $\dot{\varepsilon}$ =1/s		at $\dot{\varepsilon}$ = 0.01/s	
	Strengt h	Ductilit y	Strengt h	Ductilit y
20	25.7%	5.1%	29.4%	3.8%
50	30.0%	26.3%	37.5%	15.4%
100	34.6%	32.3%	39.3%	23.1%

3. Conclusion

To estimate the circumferential strength and ductility of Zircaloy-4 cladding tube with different oxide thickness that is equivalent to the expected burp-up, the ring tensile tests were carried out with the fast strain rate of 1/s and 0.01/s to simulate a RIA. Both the circumferential ultimate tensile strength and displacement at failure of specimens decreased with increasing the oxide thickness. The strength and the ductility of specimens that have 100μm oxide thickness were reduced by 34.6% and 32.3%, respectively from those of non-oxided ones. To qualify this test method for the estimation of the mechanical properties of cladding tubes at high burn-up, the same tests should be also carried out on the cladding tubes that have actual burn-up with the same oxide thickness.

Acknowledgement

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