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Aspect of Breakaway Oxidation of a Zirconium Alloy Cladding Tube during Oxidation at 800 ºC

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1. Introduction

Zirconium alloys have been used as fuel cladding materials in light water reactors (LWR) since the 1960s due to their low neutron absorption cross section, acceptable corrosion resistance, and good mechanical strength. However, it has been reported that zirconium alloys have some disadvantages in accident conditions such as loss of coolant accident (LOCA). As a LOCA occurs, cladding temperature increases rapidly, which causes abrupt increase of oxidation rate. One of the most critical oxidation behaviors that can occur is breakaway oxidation. As breakaway oxidation occurs, oxidation and hydrogen absorption rates increase abruptly, causing cladding to lose its mechanical integrity by increasing oxygen concentration in metal substrate and by increasing thickness of brittle phases such as α-Zr(O) and ZrO_2. It is known that zirconium alloys are vulnerable to breakaway oxidation during oxidation at 800 and 1000 ºC [1]. So far, many researches have been carried out to analyze the breakaway oxidation that occurs at 1000 ºC [2,3]. However, a few studies have been performed to characterize the breakaway oxidation that occurs at 800 ºC. Hence, in this study, aspect of breakaway oxidation that occurs on a zirconium alloy cladding tube was analyzed after high-temperature steam oxidation tests at 800 ºC.

2. Methods and Results

Experiments were performed using Zr-1Nb-1Sn-0.1Fe cladding tube specimens. The length, outer diameter, and thickness of each specimen were 40, 9.5, and 0.57 mm, respectively. After the specimens were prepared, they were oxidized in a radiant heating furnace [2]. The specimen was located between two alumina specimen holders to avoid reaction with the Inconel holder. The condition within the furnace was maintained as steam by making steam flow to the furnace 15 min before starting a test; the steam flow rate was maintained as 3.5 mg/(cm^2·s) throughout the test.

After performing oxidation tests, the microstructures of the specimens were analyzed using scanning electron microscopy (SEM). For this analysis, a small ring was cut from a specimen, and it was mounted on the hot mount resin, ground using silicon carbide papers (320,

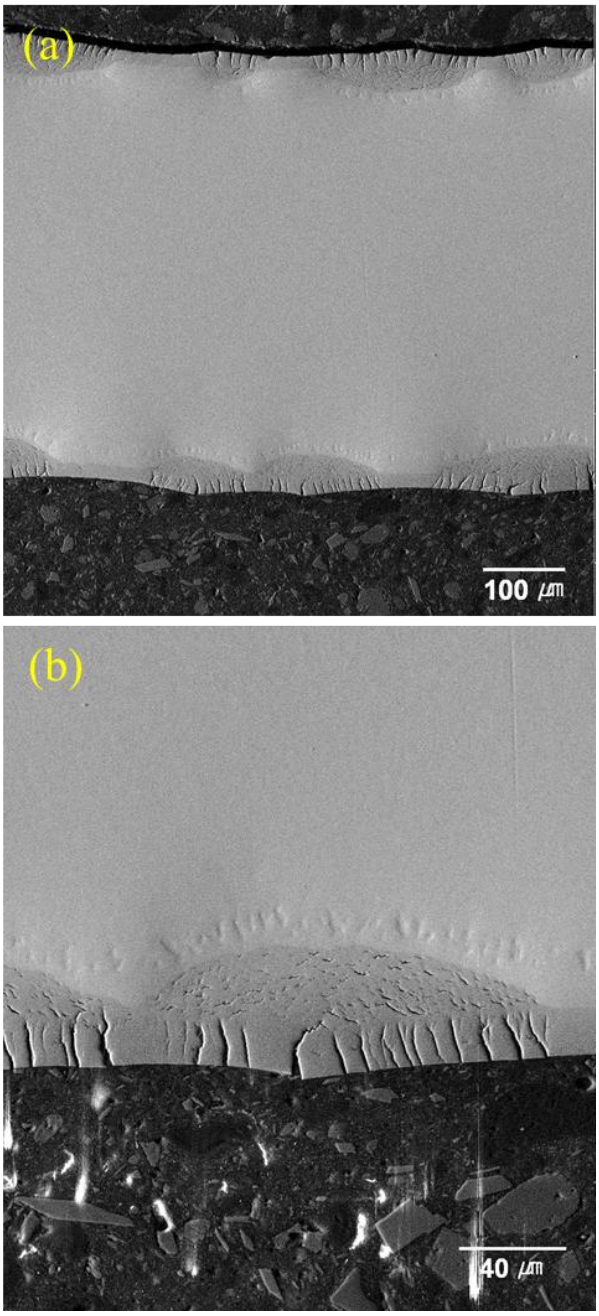

Fig. 1. SEM back scattered electron images of Zr-1Nb-1Sn-0.1Fe cladding tube after steam oxidation at 800 ºC for 12610 s.

600, and 800 grit), and polished using diamond suspensions (6, 3, and 1 mm). SEM analysis was carried out using a Quanta 200FEG in backscattered electron (BSE) mode, at an accelerating voltage of 15 kV.

3. Conclusions

Scanning electron microscopy (SEM) images of a specimen oxidized at 800 ºC for 12610 s are shown in Fig. 1. This specimen showed a severe extent of breakaway oxidation, and it is noticeable that radial cracks are formed in the oxide close to the outer surface and relatively small cracks are formed in the oxide close to the metal substrate. Comparing to the breakaway oxidation that occurs at 1000 ºC [2], microstructure aspect during breakaway oxidation at 800 ºC is very different. Analyzing the reason for this phenomenon will enhance our understanding of breakaway oxidation, and a new method improving accident resistance of zirconium alloy cladding can be proposed in the future.

REFERENCES

[1] M. Billone, Y. Yan, T. Burtseva, R. Daum, Cladding Embrittlement during Postulated Loss-of-Coolant Accidents, Argonne National Laboratory (ANL), NUREG/CR-6967, 2008.

[2] C.M. Lee, Y.-K. Mok, D.-S. Sohn, High-temperature steam oxidation and oxide crack effects of Zr-1Nb-1Sn-0.1Fe fuel cladding, J. Nucl. Mater. 496 (2017) 343–352.

[3] H.-G. Kim, I.-H. Kim, B.-K. Choi, J.-Y. Park, A study of the breakaway oxidation behavior of zirconium cladding materials, J. Nucl. Mater. 418 (1) (2011) 186-197.