Evaluation of advanced zirconium alloy developed by KEPCO NF

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1. Introduction

Zirconium-Niobium based alloys, such as ZIRLO, M5, E110 and HANA etc., have been used or developed as cladding and structural materials for nuclear reactor due to their low thermal neutron capture cross-section, adequate mechanical properties and good corrosion resistance [1, 2]. However, as the demands the high burn-up operation [3], the load-following operation [4] and the high temperature performance, several kinds of alloys have been continuously researched. KEPCO NF also has been developing the advanced zirconium alloy for the demands above. The advanced zirconium alloy is concerned that of the higher corrosion resistance, higher mechanical properties (especially fatigue property) and the formability. Approximately, three hundred types of Zirconium-Niobium based alloys were designed and corrosion tests, mechanical test and hydrogen pick-up test were conducted internally. Finally, 2 kinds of alloy (M1 and M2) were selected for the candidates of promising candidates of advanced zirconium alloy and are still on the optimization research.

In this study, the results of PWR-simulated corrosion test, the fatigue test and the high temperature oxidation test for the candidate alloys were shown to evaluate the performance.

2. Experimental procedure

The corrosion test was performed with PWR-Simulated autoclave of 360°C water under a saturated pressure of 19 MPa. Fatigue test were conducted with constant amplitude (20Hz) for the plate specimens using tensile loading with a load ratio R=0 at room temperature. Measured fatigue life for all the prepared specimens were shown in the rage (17,000 ~ 24,000) cycles at 600 MPa of stress. High temperature oxidation test was performed at 1000, 1100 and 1200°C up to 1800 sec in the steam condition.

3. Results

3.1 PWR-simulated corrosion test

The corrosion behavior of the candidate alloys and reference alloys were exposure in simulated PWR water. Fig. 1 shows the weight gain of alloys for 165 days. Between the candidate alloys and reference alloy B and C, there were not specific difference on the weight gain. However, other reference alloy A was shown much higher weight gain than the candidate alloys. Because, reference alloy A was already passed though the transition time, which shows the rapid increase in weight gain. The test will be continuously conducted until over 400 days to distinguish the differences among alloys.

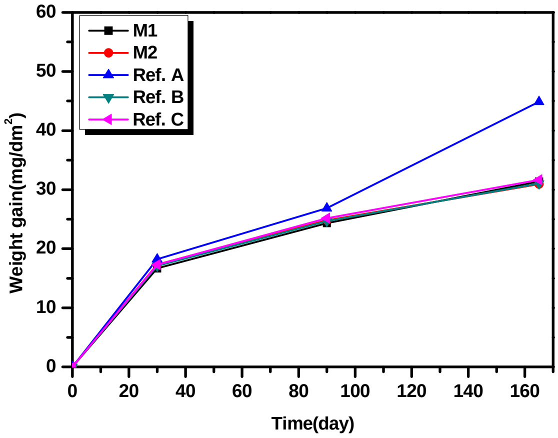

Fig. 1. The result of PWR-simulated corrosion test (165 days) of the candidate alloys and reference alloys

3.2 Fatigue test

In Fig. 2, the candidate alloys were compared with reference alloys. The candidate alloys were ruptured about 23,000 ~ 24,000 cycles and the reference alloys were ruptured about 17,000 ~ 19,000 cycle. The candidate alloys (M1 and M2) have up to 40% higher fatigue fracture resistance than those of the other reference alloys.

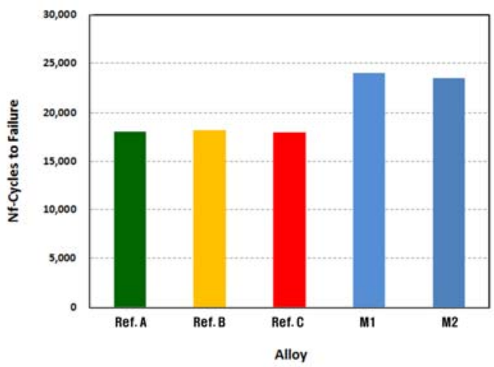

Fig. 2. The result fatigue failure cycle of alloys at 600MPa, 20 Hz

3.3 High temperature oxidation

High temperature oxidation test was conducted for the safety evaluation at high temperature. The test temperatures was determined under the peak cladding temperature at Loss of Coolant Accident (LOCA) condition. The corrosion test was performed 3 times for the reproducibility of data at each targeted temperature.

Fig. 3 presents the weight gain due to the high temperature oxidation test of candidate alloys(M1 and M2) and reference alloys(Ref. C and Ref. A). As shown in Fig. 3, the candidate alloys have relatively lower weight gain trend than those of the reference alloys. With increasing temperature for the test, the gap difference of weight gain value between the candidate alloys and the reference alloys were widened probably due to the kinetics view.

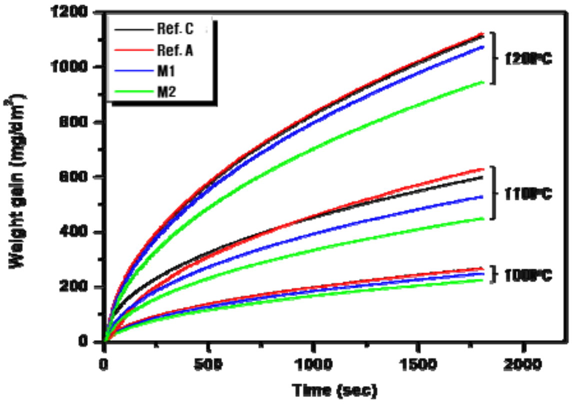

Fig. 3. The result of high temperature oxidation test at the 3 temperature (1000, 1100 and 1200^{o}C) for 1800 sec.

4. Summary

The performance of candidate alloys of advanced zirconium alloy were evaluated with the corrosion test, fatigue test and high temperature oxidation test. Based on the test results, the candidate alloys shows almost higher performance than reference alloys. However, the corrosion test is not enough to figure out the differences between the candidate alloys and the reference alloys.

To achieve better performance, the optimization of manufacturing such as anneal process and plastic working are required. Also, KEPCO NF is planning to carry out more tests for the clad tube and strip for the possibility of the high performed application.

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