Transactions of the Korean Nuclear Society Autumn Meeting
Jeju, Korea, October 21-22, 2010

Development of EMT Equipment for High Burn-up Cladding

Sang Yoon Park*, Byoung Kwon Choi, Jeong-Yong Park and Yong Hwan Jeong
Nuclear Convergence Technology Division, KAERI
Daedeokdaero 1045, Yuseong, Daejeon, 305-353, Korea
**Corresponding author : nsypark@kaeri.re.kr*

1. Introduction

Since the 1960's, fractures of cladding induced by a pellet-cladding interaction (PCI) in BWR and CANDU-type reactors have been reported [1]. With the changes in pellet shapes and the development of a barrier cladding using an inner layer of pure zirconium in BWR fuel design in the 80's, PCI has since received little attention, except for power transient conditions in a PWR. Indeed, it is well known that a cladding failure by an iodine-induced stress corrosion cracking (ISCC) may occur under PCI conditions during power transients in PWRs. Under PCI conditions, ISCC then results from the synergic effect of (i) the hoop tensile stress imposed on the cladding by fuel thermal expansions during power transients and (ii) the corrosion by iodine released from the UO2 fuel as a fission product [2-3]. Now, many power plants adopt a high burn-up operation, which includes a high power, enlarged fuel cycle, and so on. In high burn-up, the cladding becomes more brittle because of the hydride formed by waterside corrosion and the possibility of a fracture by PCI is increased [3-7]. To evaluate the PCI resistance of high burn-up cladding, ramp tests in research reactors or the expanding mandrel test (EMT) in laboratory tests have been used[8,9]. The fuel rod ramp tests are both time consuming and costly. Furthermore, expanding mandrel tests have been used to supplement fuel rod ramp test data to understand the PCI phenomenon. The segmented expanding mandrel test (SEMT) has been used for studying the PCI phenomenon and for selecting the high PCI resistant Zircaloy cladding. Because of the segmented and complex structure of the cells, reproducibility of the SEMT test results has been very limited.

Therefore, in this study, we focused on the development of new EMT equipment which has greater reproducibility and can do on-line monitoring for radial strain change. The rupture behavior of Zircaloy-4 cladding in the range of room temperature to 350^{o}C was evaluated and compared.

2. Experimental Procedure

Fig. 1 shows the conventional segmented EMT cell and a newly designed, non-segmented EMT cell. Because the Al_2O_3 segments slide and move easily and the radial expansion of Zr the slug is irregular, the reproducibility of test results for the conventional EMT cell is very low. In the newly designed EMT cell, a non-segmented / pre-notched Al_2O_3 sleeve is easily settled in the proper position for circular expansion of the drilled Zr slug, so that the reproducibility of tests using the newly designed EMT cell can be greater than those using the conventional EMT cell.

The change of cladding diameter during the test was monitored on-line by a high temperature strain gauge. EMT tests for Zircaloy-4 cladding were performed at room temperature and 350^{o}C in preliminary tests of hydrided Zircaloy-4 cladding. The effect of other experimental conditions, such as, moving speed of the plunger, strain, and iodine vapor pressure, on the rupture time will be evaluated in the future. The iodine will be introduced into the cell by letting an argon gas flow through a container with iodine crystals placed in a water bath. The partial pressure of iodine will be controlled by changing the temperature of the water bath.

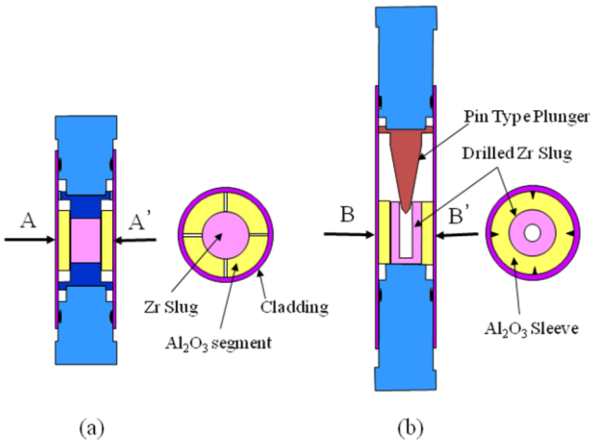

Fig.1. Schematic of the conventional (a) and newly designed (b) EMT cell

3. Results and Discussion

As showed in Fig.1, the moving distance of the newly designed plunger was prolonged much more than that of the conventional one so that the strain on the cladding could be controlled precisely. Fig. 2 shows the straining mechanism on cladding by the moving of a pin-type plunger and the ruptured Zircaloy-4 claddings by EMT test at room temperature without iodine environment. Fig. 2(c) shows the good reproducibility of the test at the point of a ruptured crack shape, crack size and cladding strain and so on. The crack length, crack width and cladding strain of the two tests were identical within the range of experimental error. For high burn-up claddings, local ductility of the cladding is changed by position to position so that the claddings have varying rupture behavior. The EMT cell for high burn-up cladding, therefore, needs to have better precision and reproducibility than it currently demonstrates.

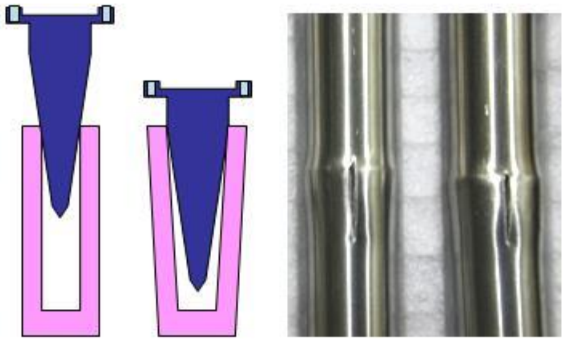

Fig. 2. Before (a) and after (b) Expansion of drilled Zr slug and the EMT tested Zircaloy-4 cladding(c)

Fig. 3 is a graph of the position controlled results tested at room temperature and 350°C showing the change of plunger load and cladding strain according to plunger position. At the sharp load drops point test cladding specimens were ruptured, as in Fig.2(c). For a high temperature tests, the specimen ruptured at the lower load and higher strain than that for low temperature tests.

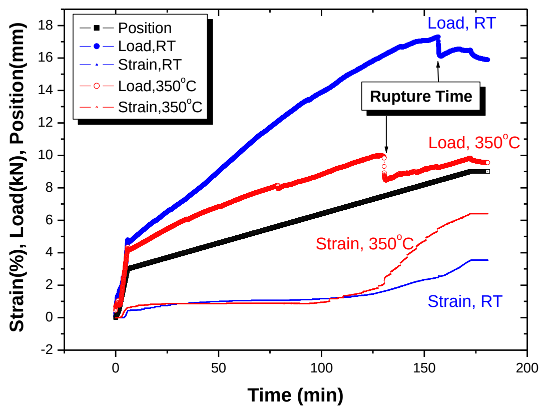

Fig. 3. Plots of strain, load and position vs. test time measured by on-line monitoring

The newly designed EMT cell has a good performance in the test without iodine at RT and high temperature as shown in Fig. 3. The effect of other experimental conditions, that is, moving speed of plunger, strain, iodine vapor pressure on the rupture time will be evaluated in the future.

4. Conclusions

A newly designed EMT cell and equipment were developed and preliminary tests for high burn-up cladding were performed. The newly designed EMT cell had a good performance in the test without iodine at RT and high temperature, as shown in Fig. 3. The effect of other experimental conditions, that is, moving speed of plunger, strain, iodine vapor pressure on the rupture time will be evaluated in the future.

REFERENCES

[1] B. Cox, *J. Nucl. Mater.*, 170, p1, 1990.
[2] R. E. Williford, J. Nucl, Mater., 132, p52, 1985.
[3] B. Cox, *J, Nucl, Mater.* 172, p 249, 1990.
[4] J. A. L. Robertson, in : proc. of Joint Topical Meeting on commercial Nuclear Fuel Techuoloh tody, Toronto, Aprial CNS-ISSN-0068-8515, 1975.
[5] F. Garzarolli, R. von Jam and H. Stehel, Energy Rev. 17, p.31, 1979.
[6] J. C. Wood and J. R. Kelm, Res Mech, 8, p 127, 1983.
[7] J. C. Wood, Nucl. Technol, 23, p63, 1974.
[8] B.N. Nobrega, J.S. King and G.S. Was, J. Nucl, Mater., 131, p99, 1985.
[9] J.P. Foster and R.A. Leasure, Simulated Fuel Expansion Testing of Zircaloy Tubing, American Society for Testing and Materials, Philadelphia, p 517-534,1989.