LOCA Behavior of E110 Alloy

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The Nuclear Safety Institute of Russian Research Center "Kurchatov Institute" (NSI RRC KI), in cooperation with the Russian State Research Center "Research Institute of Atomic Reactors" and with the support of the Joint Stock Company "TVEL" (Russian Federation), the U.S. Nuclear Regulatory Commission (USA), and the Institute for Radiological Protection and Nuclear Safety (France), is conducting a program to further study the mechanical behavior of Russian zirconium-niobium alloys under LOCA conditions. The first part of the program carried out during 2001-2002 was devoted to the experimental study of the LOCA-related ductility in E110 (Zr-1%Nb) cladding on the basis of ring compression mechanical tests [1]. These studies have shown that:

- The zero ductility threshold of the E110 alloy is lower than that of Zircaloy-4 alloy;
- An earlier initiation of the breakaway effect in nodular corrosion and the intensive absorption of hydrogen are the most significant differences in the LOCA behavior of these two alloys.

Additional tests have demonstrated that there is no correlation between the ductility threshold and the alloying elements in those alloys examined. This finding prompts a more general question: Is this oxidation behavior typical of the whole family of zirconium-niobium alloys or only the Russian cladding types?

Several approaches have been proposed to get the answer to this question. In accordance with the established plan, the needed data base will be obtained from comparative tests with M5, E110, ZIRLO, Zircaloy-2, and Zircaloy-4 alloys performed in Argonne National Laboratory [2] and on the basis of the second part of the RRC KI/RIAR program. The major focus of this stage of work is concentrated on the issues presented in Table 1.

Table 1. Major provisions of the program to reveal the factors responsible for the specific behavior of the E110 alloy

Type of possible factors	Details	Approaches to demonstrate the sensitivity of test results to different factors
1. Surface effects	Surface roughness and surface contamination	Polish and etch the cladding surface
2. Bulk effects	Chemical composition of Zr ingot	Use sponge Zr ingot instead of traditional Russian ingot (mixture of iodide and electrolytic Zr)
	Cold work variations	Use E110 tubes manufactured employing different schemes of the cold work

The experimental studies in this stage of the program have not yet been completed. However, analysis of results to date permits several conclusions:

1. The ductility of E110 oxidized cladding is very sensitive to surface effects. Etching of cladding surface leads to the increase of the breakaway phenomena and to the decrease of the cladding ductility threshold. Polishing

of the cladding surface leads to the significant improvements of cladding characteristics.

2. As for the bulk effects, several tests were performed with experimental batches of the E110 cladding. These experimental E110 cladding were manufactured using the modified procedure of the cold work and modified methods to obtain Zr ingots based on the sponge Zr instead of the traditional (for Russia) iodide/electrolytic Zr.

To illustrate the major findings of these investigations, the comparative test results are presented in Fig. 1 for the following three types of the E110 cladding:

- E110 (E110 standard cladding tube);
- G110-3f (E110 experimental cladding manufactured on the basis of French (Framatom) sponge Zr);
- G110-3ru (E110 experimental cladding manufactured on the basis of Russian sponge Zr).

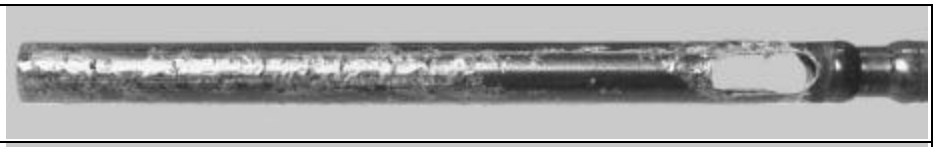
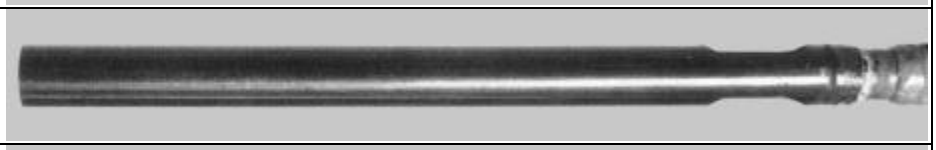
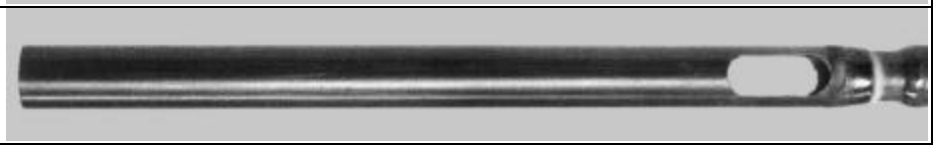
E110(standard), #96, 9.8% ECR	
G110-3f, #99, 11.5% ECR	
G110-3ru, #97, 16.7% ECR	

Fig. 1. View of different types of the E110 claddings after the double-sided oxidation at 1100 C

Initial analysis of these results allows the following conclusions:

- Zirconium-niobium claddings demonstrate a very high sensitivity to the manufacturing processes used for their fabrication;
- When tested under LOCA conditions, the ductile behavior of several experimental variations of E110 cladding is comparable to or better than that of standard Zircaloy-4 cladding.

References

[1] V.Asmolov et al. "Understanding LOCA-Related Ductility in E110 Cladding", *Proceedings of the 2002 Nuclear Safety Research Conference,* NUREG/CP-0180, March 2003, 109-125
[2] Y. Yan et al. "LOCA Results for Advanced-Alloy and High-Burnup Zircaloy Cladding", *Nuclear Safety Research Conference,* Washington, DC, October 29, 2003.