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Irradiation resistance of vacuum arc chromium coatings for zirconium alloy fuel claddings

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Abstract

Effects of high energy heavy ion irradiation on structure of chromium coatings which were deposited by cathodic arc evaporation method on Zr-based alloy (E110) substrate have been studied. Within the framework of the concept of accident-tolerant fuels claddings (ATFC) chromium coatings seems to be promising for protection of zirconium alloys from oxidation. The radiation resistance of Cr deposited coatings was studied by the void swelling investigation after irradiation with 1.4 MeV argon ions at 400 °C to doses 5, 15 and 25 dpa. Irradiation of chromium coating causes the radiation-induced isotropic growth of grain size from initial 250 to 295 nm and radiation-induced swelling up to 0.66 % under irradiation dose 25 dpa. It is mean that chromium coatings have a high resistance to irradiation and can be used as a protection of zirconium alloys fuel claddings in the frame of ATFC philosophy.

Keywords: ATFC, chromium coatings, cathodic arc evaporation, ion irradiation, voids, swelling.

1. Introduction

Zirconium alloys as fuel claddings material for light water reactors play an important role in the nuclear industry due to an optimized set of corrosion, mechanical properties and low thermal neutron absorption cross-section. However, in the case of loss of coolant accident (LOCA) scenario, the zirconium alloy cladding can no longer serve as a barrier for fuel penetration into the coolant and the environment. The drastically Zr-alloy oxidation in steam at high temperatures leads to the increase of oxide layer thickness and release of hydrogen with the formation of explosive hydrogen-oxygen mixture. After nuclear accident at the Fukushima Daiichi Nuclear Power Plant in March 2011 the concept of accident-tolerant fuel claddings (ATFC) has been proposed [1]. In the framework of this concept one of the economically advantageous and realized in the short time period (<10 years) version is the deposition of oxidation-resistant coatings on already existing zirconium alloys [2-4]. Experimental data show that chromium coatings are the attractive among a large number of investigated coatings deposited by different methods on zirconium alloys [3-5]. These coatings have the high corrosion resistance at normal operational conditions at water under the pressure [5-7] and also they have high resistance to oxidation into the steam [5, 8-10] and on air [11] under accidental conditions.

In addition to high corrosion resistance, the coatings on fuel cladding tubes should have a radiation resistance not worse than the zirconium alloy substrate. Data on radiation behavior of Cr are very limited.

The effect of irradiation on structure of bulk chromium and its alloys was studied in details in [12] at the temperature range of 550-800 °C and damage doses up to 180 dpa. These data reveal sufficiently high radiation resistance of bulk chromium in this temperature range. Information about structural transformations in chromium coatings under irradiation is limited [13-16] and is related to the coatings produced by evaporation methods. The influence of 20 MeV Kr^{8+} ions irradiation at 400 °C up to 10 dpa on interface between chromium coatings/Zircaloy-4 is studied in [17]. It is shown that under this dose the adhesion of chromium coating to zirconium doesn't become worse. Overall, good chemical and microstructural stability of the Zr/Cr interface is observed [17].

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