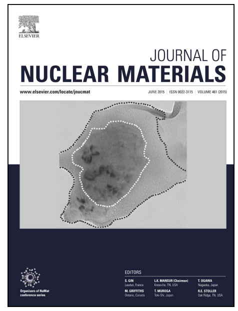
Accepted Manuscript



Vacuum-arc chromium-based coatings for protection of zirconium alloys from the high-temperature oxidation in air

A.S. Kuprin, V.A. Belous, V.N. Voyevodin, V.V. Bryk, R.L. Vasilenko, V.D. Ovcharenko, E.N. Reshetnyak, G.N. Tolmachova, P.N. V´yugov

PII: S0022-3115(15)30043-X

DOI: 10.1016/j.jnucmat.2015.06.016

Reference: NUMA 49154

To appear in: *Journal of Nuclear Materials*

Received Date: 11 August 2014

Revised Date: 29 May 2015

Accepted Date: 8 June 2015

Vacuum-arc chromium-based coatings for protection of zirconium and its alloys from the high-temperature oxidation in air

A.S. Kuprin, V.A. Belous, V.N. Voyevodin, V.V. Bryk, R.L. Vasilenko, V.D. Ovcharenko, E.N. Reshetnyak, G.N. Tolmachova, P.N. V´yugov

National Science Center "Kharkov Institute of Physics and Technology", 1, Akademicheskaya St., 61108 Kharkov, Ukraine

corresponding author: voyev@kipt.kharkov.ua

telephone/fax number: +38057-335-37-97

Abstract

Multilayer Cr-Zr/Cr/Cr-N coatings for protection of zirconium alloys from the high-temperature oxidation in air have been obtained by the vacuum-arc evaporation technique with application of filters for plasma cleaning from macroparticles. The effect of the coatings on the corrosion resistance of zirconium alloys at test temperatures between 660 and 1100 °C for 3600 s has been investigated. The thickness, structure, phase composition, mechanical properties of the coatings and oxide layers before and after oxidation tests were examined by scanning electron microscopy, X-ray diffraction analysis and nanoindentation technique

It is shown that the hard multilayer coatings effectively protect zirconium from the oxidation in air for 1 hour at test temperatures. As a result of the oxidation in the coating the CrO and Cr_2O_3 oxides are formed which reduce the oxygen penetration into through the coating. At maximum test temperature of 1100 °C the oxide layer thickness in the coating is about 5 μm,. Tthe tube shape remains unchanged independently on the alloy type. It has been found that uncoated zirconium oxidizes rapidly throughout the temperature range under study. At 1100 °C a porous monoclinic ZrO_2 oxide layer of ≥120 μm is formed that leads to the deformation of the samples, cracking and spalling of the oxide layer.

Key words: zirconium, oxidation, zirconium oxide, vacuum arc, coatings.

1. Introduction

Zr-1% Nb alloys are used as a base material of fuel claddings in the WWER-type thermal neutron reactors. The Zr-based alloys, possessing a high chemical stability provided by the zirconium oxide film, are widely applied due to their low thermal-neutron capture cross-section, good mechanical properties and high corrosion resistance in the reactor water at normal operating temperature of about 350 °C. However, in the case of accidents with raise of temperature, the zirconium cladding can no longer serve as a reliable barrier preventing the fuel penetration in the coolant and the environment. The rapid zirconium oxidation in steam at high-temperatures leads to the oxide layer thickness growth, mechanical degradation of the cladding and release of hydrogen followed by the explosive hydrogen-oxygen mixture formation. In case of an accident or handling operations, leading to the coolant loss, fuel elements can get into contact with air [1]. The air penetration into the cooling system upon the reactor shutdown is improbable but if it happens the consequences can be severe [2]. The zirconium elements are oxidizing more rapidly in air than in steam [1,2]. So, Tto prevent the fuel cladding damage, it is necessary to provide protect the zirconium alloy protection from the high-temperature corrosion in steam and in air as well.

Extensive investigations have been carried out to find out the mechanisms of the high-temperature zirconium alloy oxidation in different media [1-7] and to develop the zirconium alloy protection techniques [8-14]. It has been established that the ion implantation of different elements can change the structure and the composition of the zirconium oxide and thus improve its protective properties [8,9]. For protection of nuclear fuel in the zirconium cladding in case of an accident scenario like LOCA it is proposed to use FeCrAl alloys, as an outer capsule, due to