Cr coating with different textures: thermal stability and oxidation mechanism

Yahuan Zhao[1], Zhao Shen[1], Xiaoqin Zeng[1]

[1]National Engineering Research Center of Light Alloy Net Forming and State Key Laboratory of Metal Matrix Composites, School of Materials Science and Engineering, Shanghai Jiao Tong University, Shanghai 200240, China

zhaoyahuan@sjtu.edu.cn

Abstract In the Fukushima accident in 2011, the reactor core coolant was lost, the temperature of the fuel element increased instantaneously, and the zirconium alloy cladding reacted with high temperature water vapour in a violent oxidation reaction, generating a large amount of hydrogen and releasing a large amount of heat, which led to the melting of the core, triggering a hydrogen explosion or combustion explosion under specific conditions and leading to a large amount of radioactive material leakage. The Fukushima accident exposed the major safety hazards of UO^{2-}Zr alloy fuel elements, and accident tolerant fuel (ATF) has become a hotspot and focus of research in the nuclear industry. Compared with the traditional UO^{2-}Zr alloy fuel system, ATF is designed to enhance the ability of the fuel element to withstand severe accidents, while maintaining or even improving the fuel performance under normal operating conditions. Cr-coated zirconium alloy cladding has excellent resistance to high-temperature steam oxidation, good abrasion and water-side corrosion, as well as higher technological maturity, less difficulty in engineering applications, and higher economic benefits, which makes it one of the most promising ATF candidates for engineering applications. It has become one of the most promising ATF candidate materials for engineering applications. Domestic and foreign research work has shown that the resistance of Cr-coated zirconium alloys to high-temperature steam oxidation is significantly better than that of uncoated zirconium alloys under the accidental conditions of reactors, but there is no systematic and in-depth exploration of the micro-mechanisms of the oxidation-failure of this material system and its key influencing factors. The team used Zr_{y-4} alloy as the substrate material, and prepared pure metal Cr coatings by high-power pulsed magnetron sputtering (HiPIMS), with a target thickness of 15 μm. The Cr coatings were of elongated columnar crystalline organisation, with overall uniformity and denseness, and no loose structural defects such as pores and cracks on the surface, and were well bonded to the Zr_{y-4} substrate. The high-temperature steam oxidation experiments were carried out using a comprehensive thermal analyser, with the oxidation temperature set at 1200°C and the isothermal oxidation time up to 6000 s. The high-temperature steam oxidation behaviour of the Cr-coated zirconium alloy was

systematically investigated under the simulated reactor water loss accident conditions, to reveal the influence of the metallic Cr coating texture on the high-temperature steam oxidation behaviour of the material system and its microscopic mechanism. After the experiment, the microstructural characteristics of the oxidized samples were systematically analyzed by multi-scale high-resolution characterization techniques, focusing on the distribution characteristics of the phases and the evolution of their grain morphology, size, and orientation, to reveal the influence of the coating texture on the oxidation-decay-failure behavior of Cr-coated zirconium alloys and its microscopic mechanism.

Keywords: Cr-coated Zr alloy, High-temperature oxidation, Microstructure evolution, Mechanism

Reference

[1] Kurt A. Terrani, Accident tolerant fuel cladding development: Promise, status, and challenges, J. Nucl. Mater. 501 (2018) 13-30.

[2] Junkai Liu, Systematic investigations on the coating degradation mechanism during the steam oxidation of Cr-coated Zry-4 at 1200 °C, Corros. Sci. 202 (2022) 110310.