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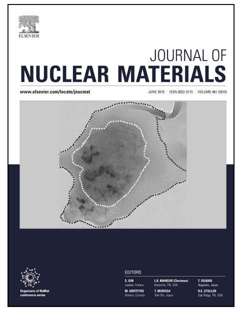

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Microstructural Evolution of NF709 Austenitic Stainless Steel Under In-situ Ion Irradiations at Room Temperature, 300, 400, 500 and 600°C

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Abstract

Irradiation induced microstructural changes in the NF709 austenitic stainless steel were investigated under 1 MeV Kr ion irradiations at room temperature (RT), 300, 400, 500 and 600°C to different doses. The irradiation-induced defects and the stability of precipitates were characterized with transmission electron microscopy (TEM). Frank dislocation loops were observed in all the irradiated samples, and the loop sizes were much larger at 600°C than those at lower temperatures. "Raft" defect structures, formed through self-alignment of small dislocation loops, were also observed in all irradiated samples. $M_{23}C_6$ precipitates were amorphorized under irradiations at RT and 300°C, but remained to be crystalline at 400°C and above. MX precipitates were stable under irradiations at RT up to 20 dpa, and at temperatures below 600°C to 3 dpa. At 600°C, some MX precipitates were observed to dissolve during in-situ irradiation, suggesting possible precipitate instability at this irradiation temperature.

Keywords: NF709, austenitic stainless steel, in-situ ion irradiation, irradiation microstructure

1. Introduction

The development of sodium-cooled fast reactor (SFR) [1,2] poses significant challenges to the reactor core structural materials, due to the anticipated elevated service temperatures and high fast-neutron fluence [3–5]. The candidate structural materials are required to have an excellent corrosion resistance and irradiation tolerance. An adequate high temperature creep strength is also needed for those candidate materials subjected to mechanical loading at high temperatures. NF709 steel, a 20Cr-25Ni-NbTiN austenitic stainless steel, has been down selected as one of the SFR candidate materials for further assessment based on its overall performance [6]. This alloy was initially developed for the ultra-supercritical power plants, and had shown an excellent creep strength as well as a satisfactory high-temperature corrosion resistance [7,8]. NF709 steel has a unique compositional combination of C and N together with Nb and Ti, which was specially tailored to maintain the material's desired properties over a long term high temperature service through the precipitation of MX type carbo-nitrides [9,10]. Compared with the extensive studies already conducted on the NF709 steel for its phase stability under thermal aging [8,9,11] and corrosion resistance [12], reports on its irradiation response are limited to date and the doses are often limited to a few displacements per atom (dpa) [13]. Long-term neutron-irradiation in a SFR at high temperatures can accelerate the dissolution of existing precipitates and possible nucleation of new types of precipitates in the NF709 steel, which may adversely affect its performance in a reactor [14]. Therefore, it is highly desirable to further evaluate the irradiation stability of the NF709 steel, even at accelerated irradiation conditions, such as the ion-irradiation.

In this study, the NF709 steel samples were in-situ irradiated using 1 MeV Kr ions at temperatures ranging from room temperature (RT) up to 600°C. The irradiation induced defects and stability of the preexisting precipitates were characterized. The objective was to provide a mechanistic understanding on the microstructural evolutions and stability of the precipitates in the NF709 steel under ion irradiations.