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Irradiation damage on $CrNbTaVW_x$ high entropy alloys

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ABSTRACT

$CrNbTaVW_x$ high-entropy alloys have been developed for plasma facing components to be applied in nuclear fusion reactors. The $CrNbTaVW_x$ (x = 1 and 1.7) compositions were prepared by ball milling and consolidated at 1600 °C under 90 MPa. To study the irradiation resistance of these materials, deuterium plasmas were used to irradiate the samples in the PF-1000U facility with 1 and 3 discharges. Structural changes before and after irradiation were analyzed by scanning electron microscopy coupled with energy dispersive X-ray spectroscopy. Nuclear reaction analysis was carried out with 1000 and 2300 keV $^3He^+$ ion beams to evaluate the profile and amount of retained deuterium on the irradiated samples. After irradiation, the sample with higher W content revealed swelling and melting for all discharges, while in the case of CrNbTaVW only blisters were observed. The deuterium retention was higher for $CrNbTaVW_{1.7}$ when compared with CrNbTaVW for 3 discharges applied.

1. Introduction

There is an urgent need to develop novel and advanced nuclear materials to guarantee that a future nuclear fusion reactor can operate continuously and safely, ensuring a long-life of the plasma facing components. Tungsten is the leading high atomic number candidate for plasma-facing components due to its high melting point, high sputtering threshold, corrosion resistance, and tensile strength [1–3]. However, one of the main drawbacks is high Ductile-to-Brittle Transition Temperature (DBTT) of tungsten, which should operate at 350–400 °C [4].

The proposed strategy to increase the fracture toughness of W includes the development of high-entropy alloys HEAs through a powder metallurgy route [5,6]. In the last few years, this multi-component systems called HEAs attracted special attention for nuclear fusion applications. HEAs are solid solutions with simple BCC (body centered cubic), FCC, (face centered cubic) or HCP (hexagonal closed packed) crystal structures with five or more elements that range between 5 and 35 at. %, an equiatomic or non-equiatomic alloy has the same or different percentage in the number of atoms, with this HEAs have a unique set of promising properties such as high hardness [7], high thermal conductivities [8] as well as high thermal [9] and irradiation [3,10,11] resistance. The numerous combinations of the elements, the production processes available, the conditions, and the environment in which the alloy will operate, were requirements remarkably difficult to achieve. There are some studies that demonstrated that HEAs exhibit a high fracture toughness such as $Ti_3Zr_{1.5}NbVAl_{0.25}$ alloy [12] which shows better combination between strength and toughness than most traditional alloys and HEAs. In addition, previous work on the present equiatomic ($CrNbTaVW_1$) and non-equiatomic HEAs ($CrNbTaVW_{1.7}$) [13] showed that the non-equiatomic alloy evidence an improvement of mechanical properties. Based on this result, it is believed that these materials have potential for the present application. However, irradiation resistance studies are necessary. For this purpose, a plasma focus machine was used that is capable to generates directed, dense hot plasma flows and fast ion streams with incident energies for light deuterium that can range from dozens of keV up to few MeV and can be suitable for fusion first wall studies. In the present experiment, HEAs were irradiated in the large Plasma Focus devices PF-1000U with deuterium plasmas. Scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy will be used to characterize the surface of the irradiated materials. In addition, nuclear reaction analysis (NRA) will identify the depth profile and quantify the deuterium retention in the exposed surfaces.

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