Irradiation Resistance of Proton, Helium ions and Electron Beam Irradiated $W_xTaTiVCr$

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1. Introduction

Tungsten (W) is a potential candidate for forthcoming fusion plasma facing applications due to its high melting temperature, high mechanical strength, low sputtering erosion and adequate thermal conductivity [1,2]. Pure tungsten shows brittleness and irradiation induced embrittlement [3]. Therefore a novel reduced activation high entropy alloy (HEA) $W_xTaTiVCr$ is being analyzed for its potential plasma facing applications. The $W_xTaTiVCr$ HEA shows enhanced mechanical strength and its ductility can be improved by adding various types of W-based reinforcements [4]. The promising mechanical behavior of this alloys turns the attention toward its irradiation characteristics as the in-service irradiation damage alters properties of materials and put the safety of reactor at risk. The analysis of irradiation resistance of $W_xTaTiVCr$ to He+ ions [5], H+ ions [6] and electrons [7] are being presented in present manuscript, because fusion reactors (ITER and DEMO) contains mixture of ionized and energetic neutral hydrogen isotopes (D and T) and He ash [8].

2. Methods and Results

2.1 Experimental

The 99.9% pure elemental powders of W, Ta, Ti, V and Cr were mixed to prepare powder mixture of $W_xTaTiVCr$. The consolidation of powder mixture was carried out by spark plasma sintering (SPS) at 1600°C for 10 minutes under 50 MPa axial pressure in vacuum environment. The ion irradiation of mirror polished samples of $W_xTaTiVCr$ was carried out at Korea Atomic Energy Research Institute (KAERI) under 200 KeV He+ ions (up to $1x10^{17}$ ions/cm^2 fluence) at room temperature. A separate batch of samples were irradiated at room temperature by 50 KeV H ions (up to $1x10^{15}$ ions/cm^2 fluence) as well. A TEM sample, prepared by JET polishing, was irradiated under 1.24 MeV electrons up to fluence of $1.12x10^{26}$/m^2 various temperatures by using High Voltage Electron Microscope (HVEM).The characterization of irradiation damage was carried out via scanning electron microscope (SEM), transmission electron microscopy (TEM). Nanoindentation test of irradiated samples was done in load control manner by iNano (Nanomechanics, Inc., USA), with a Berkovich diamond tip (radius: 50 nm). The 45 mN was applied with loading rate of 2 nm/sec for 15 s.

2.2 Results

As compare to pure tungsten which shows rough surface when subjected to 50 keV He+ ions up to fluence of $3.55x10^{18}$/cm^2 [9], the SEM microstructure of $W_xTaTiVCr$ doesn't shows any damage, as presented in Fig. 1. The H+ ion irradiated samples also exhibits similar (undamaged) microstructure of irradiated surface.

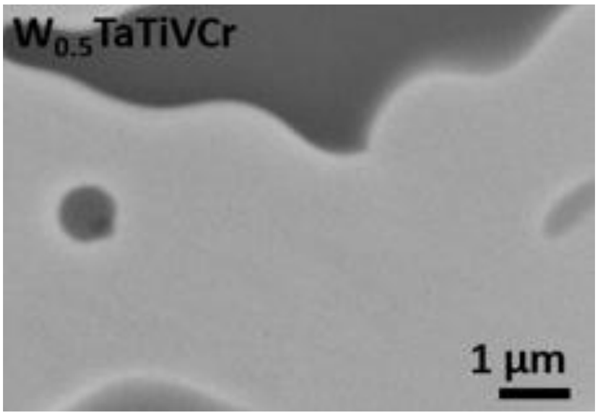

Fig. 1. SEM microstructure of He+ ion irradiated $W_xTaTiVCr$ sample.

The TEM microstructure of the irradiated materials from cross-section was examined, which shows ~200nm deep layer of irradiation damage in $W_{0.3}TaTiVCr$. The composite of $W_xTaTiVCr$ (produced to impart ductility, as discussed in introduction) having higher tungsten content in matrix material shows less depth of irradiation damage, as represented in Fig. 2.

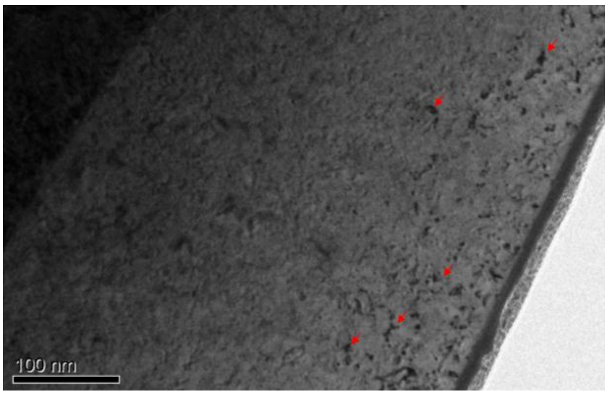

Fig. 2. Representative TEM microstructure of He+ ion irradiated $W_xTaTiVCr$.

The variation in mechanical properties due to irradiation was examined by performing nanoindentation test. Fig. 3 shows the increase in hardness of $W_{0.3}$TaTiVCr due to irradiation damage caused by 200KeV He+ ions near surface.

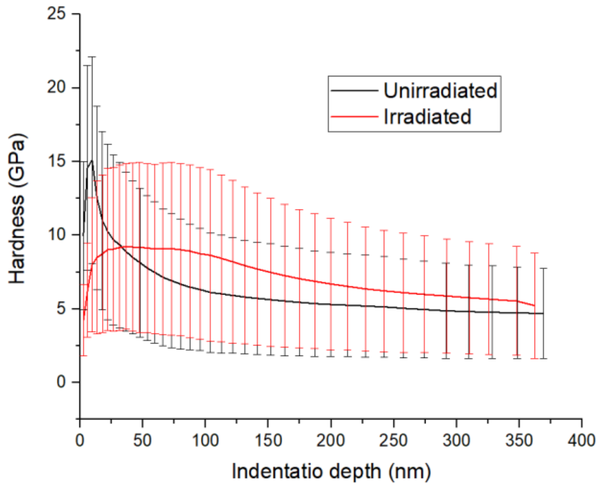

Fig. 2. Difference in hardness of Pre- and Post-irradiated (200 KeV He+ ions) $W_{0.3}$TaTiVCr.

The electron irradiation of $W_{0.5}$TaTiVCr doesn't show formation of dislocation loops due to its superior resistance to electron irradiation as compare to pure W which shows formation and growth of dislocation loops under electron irradiation [7].

Absence of irradiation induced surface roughness, irradiation damage in nanometer range, slight increase in hardness up to ~200 nm depth after He+ ion irradiation and good resistance of electron irradiation sheds the light on the potential applications of W_xTaTiVCr as fusion plasma facing material.

3. Conclusions

The analysis of He+/H+ ion and electron irradiation of WxTaTiVCr, produced by powder mixing and SPS shows enhanced irradiation resistance of this material as compare to pure W. Ion irradiation didn't cause any surface roughness. He+ ion irradiation induced damage layer and increase in hardness was limited to ~200nm depth. Moreover, no development and growth of dislocation density was observed due to electron irradiation. The enhanced irradiation resistance forecasts the potential fusion plasma facing application of this novel composites.

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