Effects of solute elements in iron-based alloys for hardness change along helium irradiation and post-irradiation annealing

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Abstract
To investigate the effect of solute Mn, Ni, and Si atoms on vacancy behavior in bcc-iron, hardness change was evaluated by nanoindentation after Helium ion irradiation and post-irradiation annealing. Irradiation-induced hardening has been confirmed in all specimens at room temperature and up to 200 ^{0}C for post-annealing, then observed the recovery.
Keywords: solute Mn-Ni-Si, post-irradiation annealing, irradiation-induced hardening

1. Introduction

In reactor pressure vessel (RPV) made of low-alloy ferrite steels, solute atoms such as Cu, Mn, Ni and Si gather to form solute clusters, and these clusters cause irradiation embrittlement of the RPV. Solute-interstitial interaction in Fe-based alloys has been studied carefully, but experimental studies on solute-vacancy interaction, especially focus on their migration mechanism are limited. Helium bubble is not usually observed in RPV, but it will be useful tool to detect vacancy migration and gathering in Fe-based steel. This study aims to investigate the effect of solute Ni, Mn, and Si atoms on irradiation-induced changes following He injection.

2. Material and Experiment

2 MeV He^{2}+ ion was irradiated in pure Fe, Fe-0.3Si, Fe-0.6Ni and Fe-1.4Mn with the fluence of 2.11×10^{16} ions/cm^2 at room temperature. These fluences are corresponding to the 0.42 dpa and 1% of helium concentration at peak. Post-irradiation annealing was conducted to the irradiated specimens at temperature range 100 ^{0}C to 400 ^{0}C with the increment of 50 ^{0}C for an hour. The indentation hardness was measured by Dynamic Ultra Micro Hardness Tester (DUH211) with the load of 18 mN to identify the microstructural change instantly. Transmission Electron Microscopy (TEM) sample was also prepared where the hardness changes largely.

3. Results

Irradiation-induced hardening has been confirmed in all specimens after irradiation at room temperature. Iron alloy contained Mn resulted the highest hardening compared to Ni and Si. Figure 1 shows the hardness changes of irradiated specimens during post-irradiation annealing. The hardening is increasing from 100 ^{0}C to 200 ^{0}C, then observed recovery. During annealing the motion of vacancies and interstitials may recover the damages, and some gathered to form voids and dislocation loops. At 400 ^{0}C, alloys Si are nearly full recovery compared to Ni and Mn alloy. Microstructures were observed. Even after the annealing at 400 ^{0}C, some microstructures were observed by TEM, especially the regions of damage peak. Further analysis using TEM will be shown in the presentation.

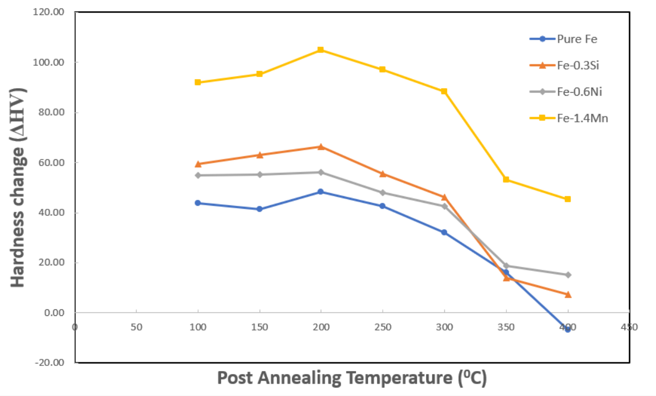

Figure 1 Hardness changes of Fe-based alloys at post-irradiation annealing temperature