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EXAFS study on irradiation-induced hardening of Fe ternary alloys

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1 Introduction

Hardening and embrittlement by the irradiation become a serious problem for nuclear reactor pressure vessel steels which have been exposed to high flux energetic neutrons for a long period. In the previous study, we have used Fe-0.6wt.%Cu binary alloy samples as a model alloy for the reactor pressure vessel alloys, and have shown that the precipitation of Cu atoms induced by energetic electron irradiation causes the hardening of the samples [1,2]. In the present report, we will show the result of the heavy ion irradiation on the hardness and atomic arrangement of Fe-Cu-Mn and Fe-Cu-Ni ternary alloys through the Vickers hardness and the EXAFS spectrum measurements.

2 Experiment

We prepared samples of homogeneous Fe-0.6wt.% Cu-1.5wt.%Mn alloy and Fe-0.6wt.%Cu-1.5wt.%Ni alloy by the thermal treatment at 800C. Such samples were irradiated with 16eV Au ions at 523K by using a tandem accelerator of QST-Takasaki. The Au ion fluences were $3x10^{14}/cm^2$ and $3x10^{15}/cm^2$. The change in hardness by the irradiation was measured by means of the Vickers hardness tester. To observe the local structures near Cu, Mn or Ni atoms in Fe matrix, the EXAFS spectra were obtained around the Cu-K, Mn-K and Ni-K absorption edges by using the KEK photon factory.

3 Results and Discussion

Figs. 1and 2 show the EXAFS-FT spectra for Fe-0.6wt.% Cu-1.5wt.%Mn alloy irradiated with 16MeV Au ions near Cu-K absorption edge and Mn-K absorption edge, respectively. In the figures, the spectra for the irradiated surface (red curves) and those for the unirradiated surface (blue curves) are compared. The shapes of the EXAFS spectra for the both surfaces show the BCC structure. The result means that Mn and Cu atoms occupy the regular BCC sites of Fe matrix before and even after the irradiation. The ion irradiation decreases the spectrum intensity. The decrease in the spectrum intensity by the irradiation is much more remarkable for the Cu-K edge than for Mn-K edge. Figs. 3 and 4 show the EXAFS-FT spectra for Fe-0.6wt.% Cu-1.5wt.%Ni alloy irradiated with 16MeV Au ions near Cu-K absorption edge and Ni-

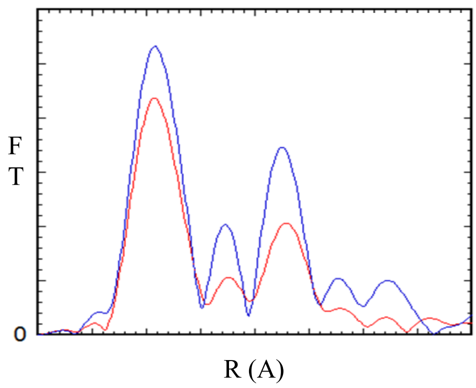

Fig.1 EXAFS-FT spectra around Cu-K absorption edge for Fe-0.6wt.%Cu-1.5wt% Mn alloy. Blue line: for unirradiated surface, and red line: for irradiated surface. Irradiation fluence is $3x10^{15}/cm^2$.

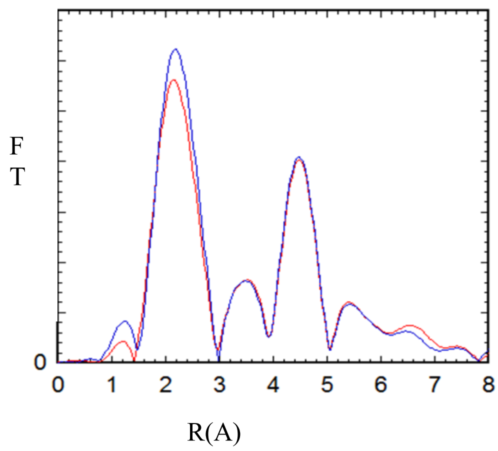

Fig.2 EXAFS-FT spectra around Mn-K absorption edge for Fe-0.6wt.%Cu-1.5wt% Mn alloy. Blue line: for unirradiated surface, and red line: for irradiated surface. Irradiation fluence is $3x10^{15}/cm^2$.

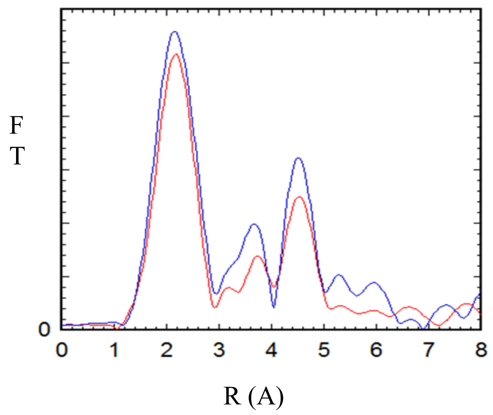

Fig.3 EXAFS-FT spectra around Cu-K absorption edge for Fe-0.6wt.%Cu-1.5wt% Ni alloy. Blue line: for unirradiated surface, and red line: for irradiated surface. Irradiation fluence is $3x10^{15}/cm^2$.

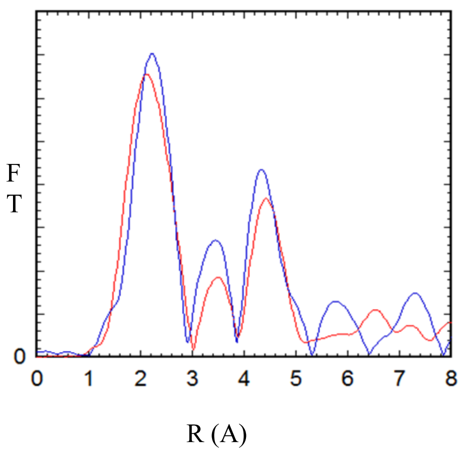

Fig.4 EXAFS-FT spectra around Ni-K absorption edge for Fe-0.6wt.%Cu-1.5wt% Ni alloy. Blue line: for unirradiated surface, and red line: for irradiated surface. Irradiation fluence is $3x10^{15}/cm^2$.

K absorption edge, respectively. The decrease in spectrum intensity is observed by the irradiation, and the decrease in spectrum intensity is about the same for Cu-K edge and Ni-K edge. Generally, the disordering of atomic arrangements (the increase in Debye Waller factor) and/or the decrease in coordination number of neighbour atoms cause the decrease in EXAFS intensity. In the present case, the spectrum decrease by the irradiation can be explained as due to the segregation of Cu, Ni and/or Mn atoms around Cu and Ni atoms, which causes the increase in the Debye Waller factor. As the decrease in EXAFS spectrum intensity for Mn-K edge is quite small, the segregation of added elements around Mn atoms scarcely occurs during the irradiation. The segregation around the added Cu and Ni elements leads to the nucleation and the growth of small clusters in Fe matrix. Such Cu and Ni clusters act as effective obstacles against the dislocation motion, and cause the hardening of the alloys. As can be seen in Figs. 5 and 6, the Vickers hardness surely increases by the Au ion irradiation for the both alloys.

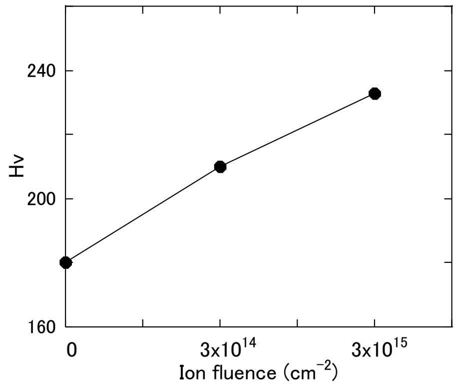

Fig.5 Vickers hardness as a function of Au ion fluence for Fe-0.6wt.%Cu-1.5wt%Mn alloy.

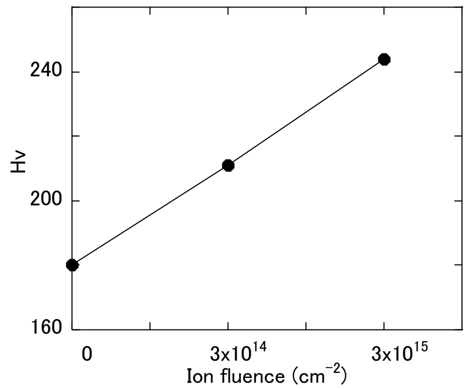

Fig.6 Vickers hardness as a function of Au ion fluence for Fe-0.6wt.%Cu-1.5wt%Ni alloy.

References
[1] T. Tobita et al., J. Nucl. Mater. 452(2014) 241-247.
[2] Y. Fujimura et al., Nucl. Instr. Meth. B354(2015) 120-124.

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