Effects of Dose Rate on Radiation Hardening in Fe and Fe-Cu Alloys under Heavy Ion and Fast Neutron Irradiation

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The effect of dose rate on irradiation hardening in Fe and Fe-Cu alloys is investigated using heavy ion irradiation. Lower dose rate enhances hardening in the specimens. In Fe-Cu alloys, irradiation-enhaced diffusion of Cu atoms by vacancies causes Cu precipitates which are the major factors for hardening.

1. Introduction

Dose rate has been widely recognized to influence radiation embrittlement in pressure vessel steels. In this study, pure Fe and Fe-Cu alloys were irradiated with heavy ions to examine dependence of surface hardening on dose rate and other irradiation parameters. Modeling of microstructural evolution in these alloys is discussed comparing the obtained results with neutron irradiation data.

2. Experimental

Specimens used in this study were 2 kinds of pure Fe (99.9% and 99.99%), Fe-0.3Cu and Fe-0.6Cu alloys. The specimens were annealed at 930°C for 1 hour and at 850°C for 2 hours. They were irradiated with 4 MeV Ni^{3+} ions from 10^{-3} dpa to 20 dpa at 240 and 290°C in the HIT facility of the University of Tokyo. Micro-vickers hardness of the ion-irradiated surface was measured at the load of 5 g. Effects of dose rate between 7 x 10^{-5} and 2 x 10^{-3} dpa/sec on hardening in ion-irradiated specimens were also studied at the fixed dose of 0.2 dpa at 240, 290 and 400°C. These specimens were also irradiated with fast neutrons to 4 x 10^{-4} dpa at the dose rate of 2.5 x 10^{-9} dpa/sec at 240 and 290°C in the YAYOI reactor of the University of Tokyo.

3. Results and Discussion

Irradiation hardening in Fe-Cu alloys was found to increase with dose at 240°C up to 20 dpa. Nucleation of Cu precipitates is considered to play an important role in the hardening in Fe-Cu alloys. Irradiation enhanced over-aging was observed by coarsening of Cu precipitates is caused by irradiation.

Hardening rate in neutron-irradiated specimens was larger than the simple interpolation of ion-irradiation data. In the ion-irradiated specimens to 0.2 dpa, hardening at lower dose rate was found to be larger than those at higher dose rate as shown in Figs. 1 and 2 at 290 and 400°C, respectively. Irradiation hardening in Fe-Cu alloys was found to be strongly enhanced at lower dose rate especially at lower temperature. Hardening in pure Fe, however, was not strongly influenced by ion dose rate. Fig. 3 shows temperature dependence of irradiation hardening with several levels of dose rates. Large difference of irradiation hardening is observed between 240 and 290 °C, whereas no large difference is detected between 60 and 240°C in all the specimens at the dose rate of 1 x 10^{-4} dpa/sec. Fig. 4 summarizes temperature dependence of irradiation hardening in Fe-0.6Cu for several levels of irradiation dose comparing neutron irradiation data.

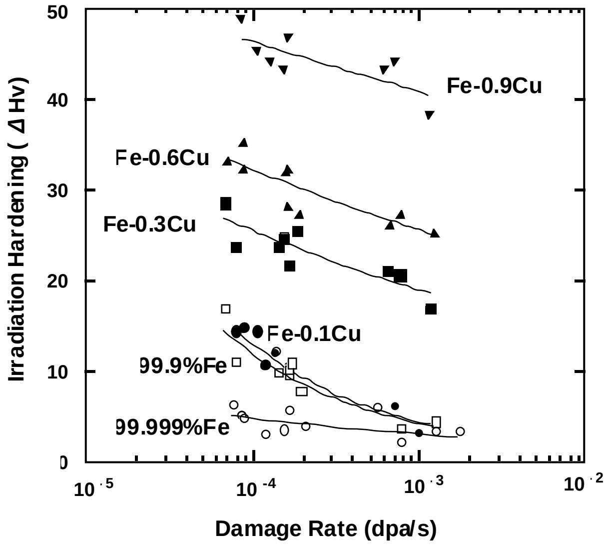

Fig. 1 Dose rate dependence of irradiation hardening at 0.2 dpa at 290°C.

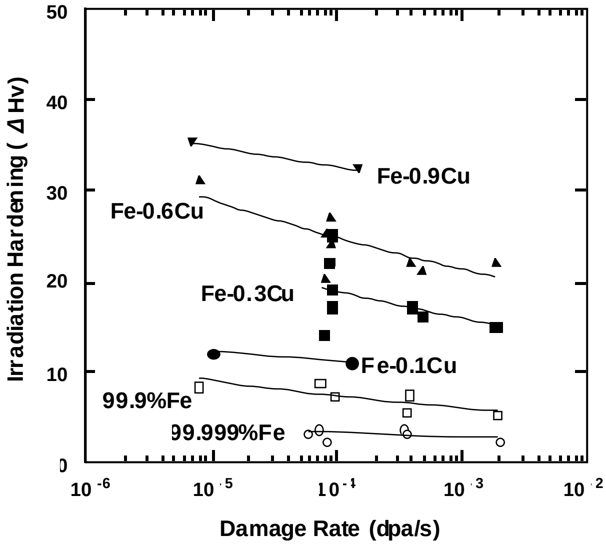

Fig. 2 Dose rate dependence of irradiation hardening at 0.2 dpa at 400°C.

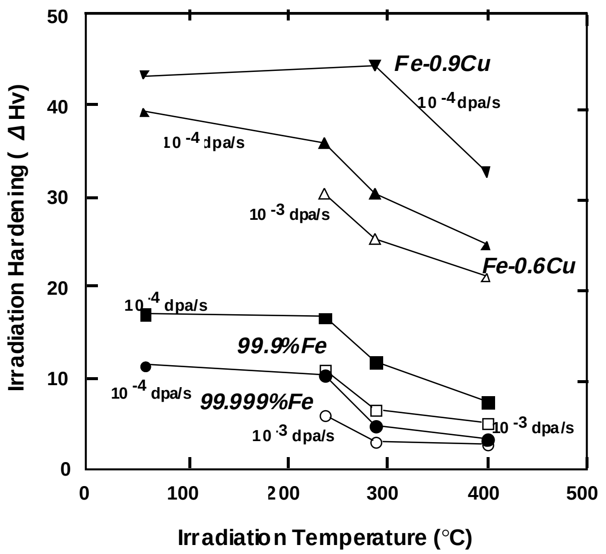

Fig. 3 Temperature dependence of irradiation hardening at 0.2 dpa for 2 levels of dose rates.

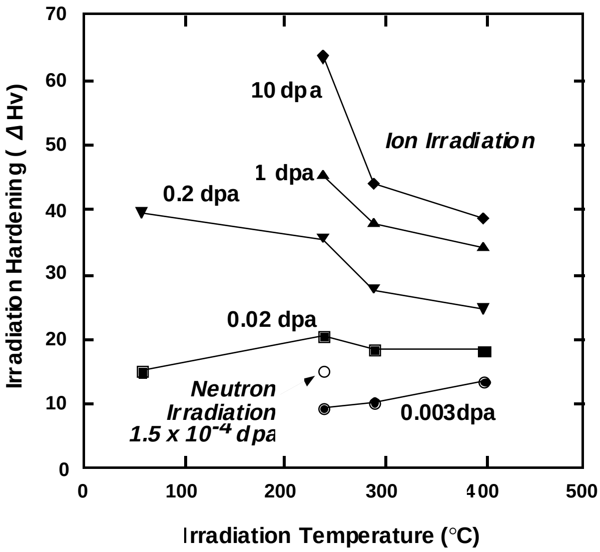

Fig. 4 Irradiation hardening in Fe-0.6Cu at several doses.