1.2 IRRADIATION HARDENING BEHAVIOR OF F82H AND NICKEL-DOPED F82H - M. Ando, H. Tanigawa, E. Wakai (Japan Atomic Energy Agency), J. P. Robertson and Y. Katoh (Oak Ridge National Laboratory)

OBJECTIVE

It is important to predict the helium effects on mechanical properties of reduced activation ferritic/martensitic (RAFM) steels in fusion blanket structural materials. For example, isotope ^{58}Nickel can generate helium atoms by the $^{58}Ni(n, \gamma)^{59}Ni(n, \alpha)^{56}Fe$ reaction. However, it is also reported that heavy irradiation hardening occurs in Nickel-doped ferritic/martensitic steels. The objective of this JAEA-USDOE collaborative study is to compare the irradiation hardening behavior of F82H with that of Nickel-doped F82H after ion irradiation or neutron irradiation experiments.

SUMMARY

For ion irradiation, the irradiation hardening behavior of Nickel-doped F82H steels is similar to that of F82H for 633 K irradiation. However, heavy hardening resulted in Nickel-doped F82H steels irradiated at 543 K. This heavy hardening was especially remarkable after only low dose irradiation. For neutron irradiation, heavy irradiation hardening occurred in the 1.4% Nickel-doped F82H up to 20 dpa; however irradiation hardening of 1.4% Nickel-doped F82H after 80 dpa irradiation is the same level for that of F82H. These results show that the helium effect of mechanical properties in F82H can be examined using F82H and Nickel-doped F82H after high-dose irradiation.

PROGRESS AND STATUS

Introduction

Reduced activation ferritic/martensitic steels (RAFM) are the most promising candidates for blanket structural materials of fusion reactors. Some transmutation products (mainly helium atoms) are produced by high-energy neutrons in the first wall of a fusion reactor. Thus it is important to understand the effects of helium production on material properties. However, helium atoms are rarely produced in F82H by neutron irradiation in a fission reactor. Therefore, to investigate the effects of helium on material properties for RAFM, some results of isotope tailoring experiments using the reaction of $^{10}B(n, \alpha)^{7}Li$ or $^{58}Ni(n, \gamma)^{59}Ni(n, \alpha)^{56}Fe$ in RAFM doped with ^{10}B or ^{58}Ni have been reported [1-4]. It is well known that heavy irradiation hardening occurs in Nickel-doped F82H at low dose at ~573K in spite of a low helium production rate. For this reason, it is difficult to separate the effects of nickel-doping from helium generation after high-dose irradiation.

The objectives of this study are to examine the irradiation hardening behavior of F82H and Nickel-doped F82H using ion irradiation experiments and high-dose neutron irradiation.

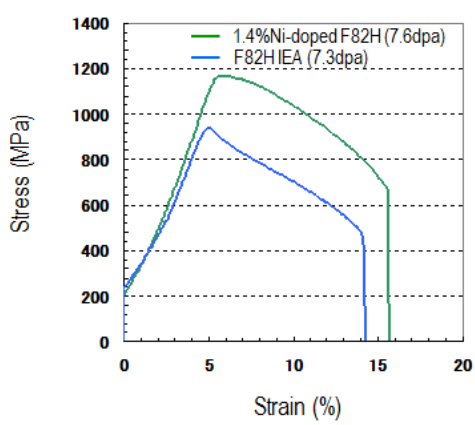

Figure1. Tensile result of F82H IEA and 1.4%Ni-doped F82H neutron irradiated at ~573 K, then tested at room temperature.

Experimental

The materials used in this study were RAFM steel (F82H IEA; Fe-8Cr-2W-0.2V-0.04Ta-0.1C [5]), and 0.5, 1.0 and 1.4%Nickel-doped F82H [6]. Each material was cut into small coupon type specimens (dimensions are 6×3×0.8 mm^3, Figure 2). One of the 6x0.8 mm^2 sides was irradiated after polishing with SiC paper #4000, 0.3 μm alumina powder, and finally to an electrolytic surface polishing. These specimens were irradiated at 543 or 633 K in the TIARA facility (JAEA Takasaki in Japan) by 10.5 MeV Fe^{3+} ions. Figure 3 shows a depth profile of displacement damage in F82H. The irradiation was performed up to ~43 dpa at the depth of ~0.6 μm from surface and the damage rate was about 10^{-3} dpa/s at this depth. Micro-indentation tests were performed at about 30points for each specimen and test condition with a load to penetrate up to 0.4 μm using an UMIS-2000 (CSIRO). The shape of the indenter tip was a Berkovich tip.

Neutron irradiation was performed in the High Flux Isotope Reactor (HFIR) to atomic displacement levels up to 80 dpa in JP28/29 capsules [7]. In this experiment, F82H IEA and two types of 1.4%Nickel-doped F82H were prepared. One was 1.4%^{58}Nickel-doped F82H which produced helium atoms during irradiation. The other was 1.4%^{60}Nickel-doped F82H which did not produce helium atoms. The hardness of some specimens irradiated at ~573 or ~673 K was measured by a Vickers hardness tester (Mitsutoyo AAV-500) at cell 2 in Building 3025E [8].

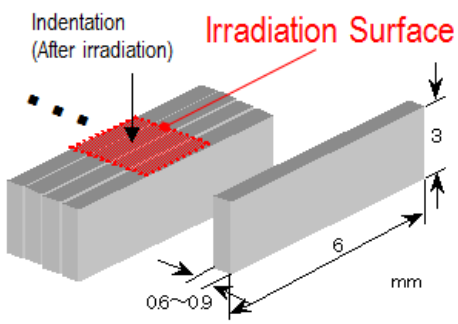

Figure 2. Illustration of coupon type specimens for ion irradiation

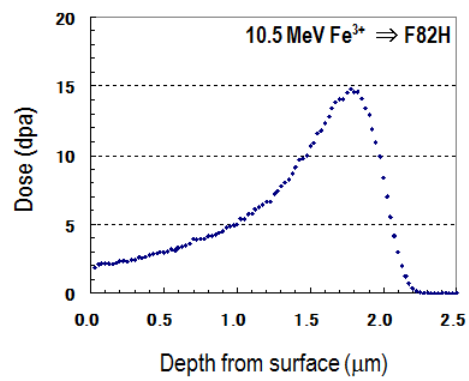

Figure 3. The depth profile of displacement damage in F82H at TIARA Facility

Results and Discussion

Figure 4a) and b) show the relationship between irradiation hardening ($100x\Delta H_m/H_m$) and irradiation dose of F82H and Nickel-doped F82H steels after ion irradiation. As the irradiation dose increases, the irradiation hardening increases for F82H irradiated at 543 and 633 K. The irradiation hardening behavior of each of the Nickel-doped F82H steels is similar to that of F82H for 633 K irradiation. However, a heavy hardening resulted in the Nickel-doped F82H steels irradiated at 543 K. This heavy hardening is especially remarkable for low dose irradiation. These results show the irradiation hardening results from a similar mechanism in F82H and Nickel-doped F82H steels irradiated at 633 K; however another hardening mechanism is possibly included in the Nickel-doped F82H steels irradiated at 543 K.

After high-dose ion irradiation, the irradiation hardening in F82H and Nickel-doped F82H was close to the same level. Therefore, it seems suitable to determine helium effects on mechanical properties of these F82H steels at higher neutron doses. Finally, 1.4% Nickel-doped F82H was selected for the neutron irradiation experiment because the irradiation hardening behavior was almost the same in 0.5-1.4% Nickel-doped F82H.

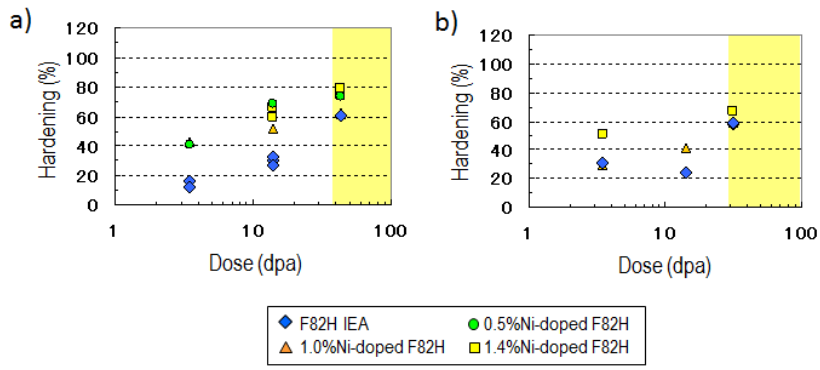

Figure 4. Dose dependence of irradiation hardening ($100x\Delta H_m/H_m$) for F82H IEA, 0.5, 1.0 and 1.4% Ni-doped F82H ion irradiated at TIARA. a) After 543 K irradiation. b) After 633 K irradiation.

Figure 5a) and b) show the dose dependence of irradiation hardening (100xΔHv/Hv) of F82H and 1.4% Nickel-doped F82H after neutron irradiation. It seems to be qualitatively similar to the behavior of ion irradiated specimens. Heavy irradiation hardening is observed in the 1.4% ^{58}Nickel-doped and ^{60}Nickel-doped F82H up to 20 dpa at ~573K, however irradiation hardening of 1.4%Nickel-doped F82H after 80 dpa (~800 appm helium) irradiation is at the same level as for that of F82H. For ~673K irradiation, 1.4% ^{58}Nickel-doped F82H, which produced helium (~200 appm helium), shows slightly more irradiation hardening than 1.4%^{60}Nickel-doped F82H. It is possible that the extra-hardening in this temperature range was caused by the production of small helium bubbles.

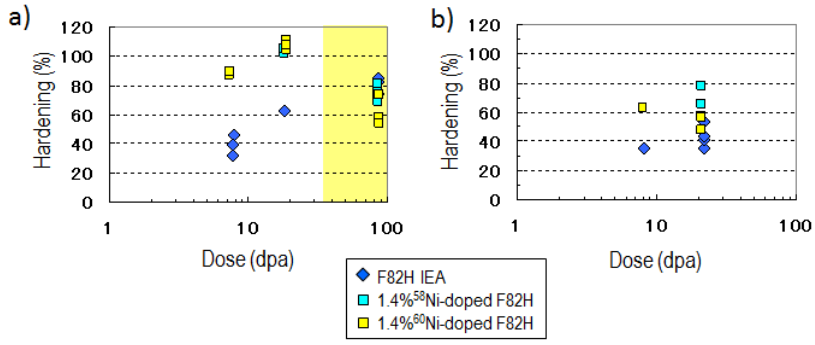

Figure 5. Dose dependence of irradiation hardening (100xΔHv/Hv) for F82H IEA and 1.4% Ni-doped F82H neutron irradiated in HFIR. a) After ~573K irradiation. b) After ~673K irradiation (No tests at ~80 dpa).

These results show that the helium effects on mechanical properties of F82H can be examined using F82H and Nickel-doped F82H after high-dose irradiation because heavy irradiation hardening decreases in Nickel-doped F82H. Future plans are for tensile and fracture toughness tests of these specimens after completion of Vickers hardness testing.

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