MICROSTRUCTURE OF ISOTOPICALLY-TAILORED F82H AND HT9 IRRADIATED AT 400°C IN HFIR - N. Hashimoto, J.P. Robertson, A.F. Rowcliffe (Oak Ridge National Laboratory), Y. Miwa , and K. Shiba (Japan Atomic Energy Research Institute)

OBJECTIVE

The objective of this report is to present recently generated TEM data for isotopically-tailored ferritic/martensitic steels, F82H and HT9, irradiated in the temperature range for swelling.

SUMMARY

Microstructures of reduced-activation ferritic/martensitic steels, F82H (8Cr-2W-0.2V-0.04Ta), 8Cr-2WVTa doped with ^{58}Ni, HT9 (12Cr-1MoVW) and HT9 doped with ^{58}Ni, irradiated at 400°C to 7 dpa in the High Flux Isotope Reactor (HFIR), were investigated by transmission electron microscopy. Cavities were observed in the standard F82H (F82H-std.) and 8Cr-2WVTa-^{58}Ni, but not in the standard HT9 (HT9-std.) and HT9-^{58}Ni alloys. The irradiation induced $\mathbf{a_0}$<100> and ($\mathbf{a_0}$/2)<111> type dislocation loops in all alloys; the number density and the mean diameter of ($\mathbf{a_0}$/2)<111> type loops were lower and smaller than that of $\mathbf{a_0}$<100> type loops. Also, there is a tendency that the number density of loops in the F82H and 8Cr-2WVTa-^{58}Ni alloys were lower than those in the HT9 alloys.

PROGRESS AND STATUS

1. Introduction

Ferritic/martensitic steels are attractive candidate structural first wall materials for fusion reactors [1]. The high-energy neutrons produced by the D-T fusion reaction induce displacement damage and generate gas atoms in the materials from (n,p) and (n,α) reactions. Simultaneous production of helium atoms from (n,α) reactions is considered to strongly influence the nucleation processes of cavities. To clarify the effect of helium atoms on the microstructural development and mechanical property changes in ferritic/martensitic steels under fast neutron irradiation, F82H (8Cr-2W-0.2V-0.04Ta), 8Cr-2WVTa doped with ^{58}Ni, HT9 (12Cr-1MoVW) and HT9 doped with ^{58}Ni were irradiated with neutrons in the High Flux Isotope Reactor (HFIR). Irradiation of ^{58}Ni-doped alloys in a mixed spectrum reactor like the HFIR results in the following transmutation reaction with the thermal neutrons:

^{58}Ni (n,γ) ^{59}Ni(n,α) ^{56}Fe

Thus this nickel doping allows for the simultaneous production of helium and displacement damage.

2. Experimental Procedure

F82H, 8Cr-2WVTa doped with ^{58}Ni, HT9, and HT9 doped with ^{58}Ni were included in this experiment; the compositions and heat treatment are given in Table 1. The heat treatment for 8Cr-2WVTa-^{58}Ni was not enough so that there is a possibility that it has much carbon in matrix. Standard 3-mm diameter transmission electron microscopy (TEM) disks were punched from 0.25-mm thick sheet stock. Irradiation was carried out at 400°C in the HFIR-MFE-JP-20 capsule in the High Flux Isotope Reactor (HFIR) to neutron fluences of ~ 5.16 x 10^{25} n/cm^2 (E> 0.1 MeV), resulting in displacement values of about 7.4 dpa. The details of the design, construction, and installation of JP-20 have been reported [2-5]. The damage level and helium concentration in the steels are given in Table 2.

Table 1. Chemical compositions of the specimens (wt.%) (Balance Fe) and heat treatment.

Steel	Cr	^{n}Ni	^{58}Ni	Si	C	N	P	S	Mn	W	V	Ta	Ti	Nb	Mo	B
HT9-std.	12.0	0.5	-	0.18	.20	.02	-	-	0.5	0.5	0.3	-	-	.01	1.0	-
HT9-^{58}Ni	12.0	-	1.4	0.18	.20	.02	-	-	0.5	0.5	0.3	-	-	.01	1.0	-
F82H-std.	7.46	0.03	-	0.14	.100	.002	.001	.001	0.49	2.00	0.20	.04	.008	-	-	.0004
8Cr-2WVTa-^{58}Ni	8.00	-	1.40	0.21	.043	.004	.001	.003	0.40	2.11	0.20	.04	.001	-	-	-

Heat treatment:
HT9-std. and HT9-^{58}Ni; 1050°C/1 h/ AC + 780°C/2.5 h/ AC
F82H-std.; 1040°C/0.5 h/ AC + 740°C/2 h/ AC

Table 2. Damage level and helium concentration.

	dpa	appm He	He/dpa
HT9-std.	7.4	10	1.3
HT9-^{58}Ni	7.4	40	5.2
F82H-std.	7.4	8	1.0
8Cr-2WVTa-^{58}Ni	7.4	50	6.6

TEM specimens were thinned using an automatic Tenupole electropolishing unit located in a glove box. TEM disks were examined using a JEM-2000FX (LaB_6) transmission electron microscope equipped special objective lens polepiece that lowers magnetic field at the ferromagnetic specimen. The foil thicknesses were measured by thickness fringes in order to evaluate quantitative defect density values.

3. Results and discussion

3.1 Dislocations and dislocation loops

Figure 1 shows the dislocation segments and loops which were obtained in HT9-std. and HT9-^{58}Ni after irradiation at 400 °C to 7.4 dpa using the diffraction conditions: **B**=[001], **g**=200, (**g**, 4**g**). The irradiation induced **a**<100> and (a_0/2)<111> type dislocation loops in both alloys, the number density and the mean diameter of (a_0/2)<111> type loops are lower and smaller than those of **a**<100> type loops. On the other hand, there is no significant difference in number density and mean diameter of loops between HT9-std. and HT9-^{58}Ni. Figure 2 shows the dislocation segments and loops which were obtained in F82H-std. and 8Cr-2WVTa-^{58}Ni after irradiation at 400°C to 7.4 dpa using the diffraction conditions: **B**=[011], **g**=200, (**g**, 4**g**). The irradiation induced **a**<100> and (a_0/2)<111> type dislocation loops in both alloys, and the number density and the mean diameter of (a_0/2)<111> type loops are lower and smaller than those of **a**<100> type loops. And, the number density and the mean diameter of loops in 8Cr-2WVTa-^{58}Ni are higher and smaller than that in F82H-std. From comparison between the HT9 and the F82H, it appears that the number density of loops in the F82H are lower than those in the HT9. Table 3 summarizes the quantitative results of dislocation loops and total dislocation density.

Table 3. The summary of dislocation loops in alloys after irradiation at 400°C to 7.4 dpa in HFIR.

Steel	a_0<100> type loops		(a_0/2)<111> type loops		Total
	Number density (m^{-3})	Mean diameter (nm)	Number density (m^{-3})	Mean diameter (nm)	density (m^{-2})
HT9-std.	1×10^{22}	14	3×10^{21}	10	6×10^{14}
HT9-^{58}Ni	1×10^{22}	16	5×10^{21}	8	6×10^{14}
F82H-std.	6×10^{21}	16	2×10^{21}	8	4×10^{14}
8Cr-2WVTa-^{58}Ni	7×10^{21}	11	3×10^{21}	9	4×10^{14}

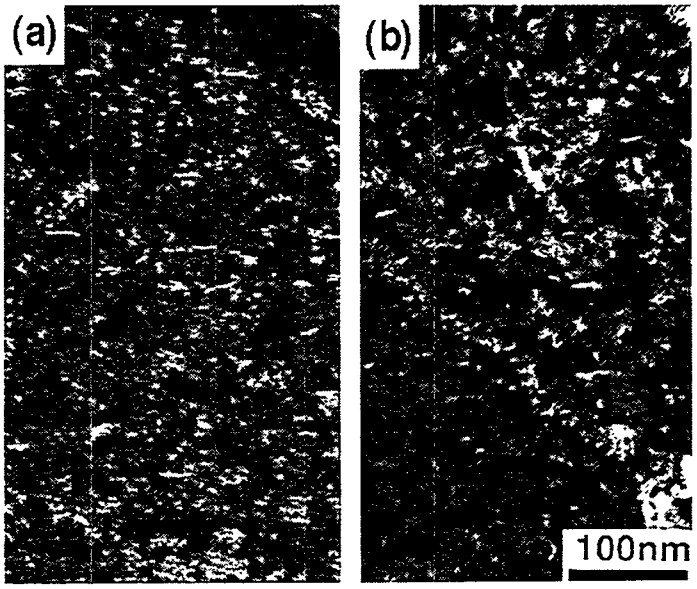

Figure 1 Microstructures of the dislocation segments and loops in HT9-std. (a) and HT9-^{58}Ni (b) after irradiation at 400°C to 7.4 dpa in HFIR, the diffraction conditions: **B**=[001], **g**=200, (**g**, 4**g**).

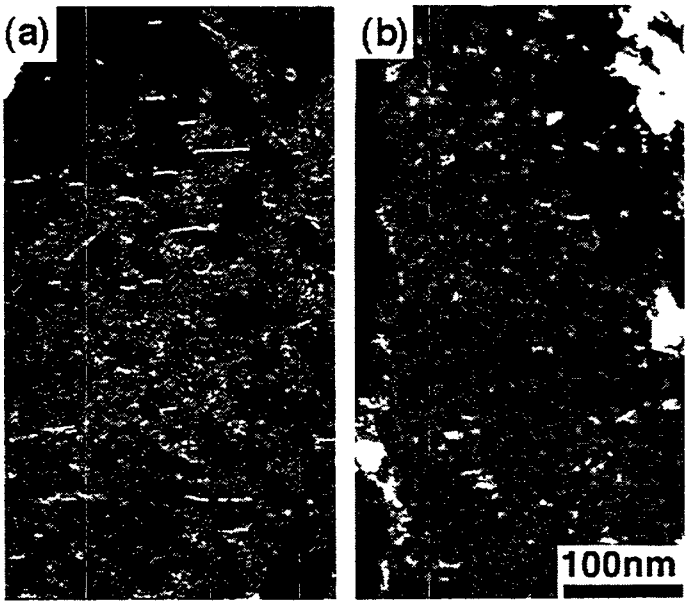

Figure 2 Microstructures of the dislocation segments and loops in F82H-std. (a) and 8Cr-2WVTa-^{58}Ni (b) after irradiation at 400°C to 7.4 dpa in HFIR, the diffraction conditions: **B**=[011], **g**=200, (**g**, 4**g**).

During irradiation of Fe-Cr binary alloys, dislocation evolution in an initially almost dislocation-free condition proceed by the formation of interstitial-type dislocation loops with an $\mathbf{a}_0$<100> and/or ($\mathbf{a}_0$/2)<111> Burgers vector [6,7]. According to an investigation of dislocation loop evolution in ferritic alloys irradiated to high fluence [8,9], the $\mathbf{a}_0$<100> type dislocation loops were sensitive to chromium content, and a number of $\mathbf{a}_0$<100> type dislocation loops were present in an Fe-12Cr alloy irradiated at 420°C to 140 dpa, while in Fe-6Cr and Fe-9Cr alloys, their number density was

extremely low. This difference in the nucleation of interstitial loops could be explained by chromium stabilization of interstitial clusters, and/or the α' precipitation promotes the loop nucleation in the Fe-12Cr alloy. Further analysis concerning the nucleation of precipitates under irradiation should be carried out. On the other hand, according to a previous paper which investigated the relationship between type of dislocation loop and content of interstitial impurities, there is a tendency for the a_0<100> type loops to form in alloys which have much carbon [10]. The HT9 alloys and 8Cr-2WVTa-^{58}Ni used in this study have more carbon and nitrogen than the F82H, which means there is a possibility that the difference in impurity content affects the loop formation.

3.2 Cavities

Figure 3 (a) - (d) show the microstructures in HT9-std., HT9-^{58}Ni, F82H-std. and 8Cr-2WVTa-^{58}Ni after irradiation at 400°C to 7.4 dpa. No cavities were observed in HT9-std. and HT9-^{58}Ni, while in F82H-std. and 8Cr-2WVTa-^{58}Ni, cavities were observed with number densities of 4×10^{21} and 5×10^{21} m^{-3}, and mean diameters of 4 and 2 nm, respectively. From this result, swelling of F82H-std. and 8Cr-2WVTa-^{58}Ni was estimated to be 0.2 and 0.018 %, respectively. Table 4 contains the cavity number densities, mean diameters and swelling of the alloys

Table 4. The summary of cavities in alloys after irradiation at 400°C to 7.4 dpa in HFIR.

Steel	Cavity		
	Number density (m^{-3})	Root mean cube (nm)	Swelling (%)
HT9-std.	-	-	-
HT9-^{58}Ni	-	-	-
F82H-std.	4×10^{21}	4	0.2
8Cr-2WVTa-^{58}Ni	5×10^{21}	2	0.018

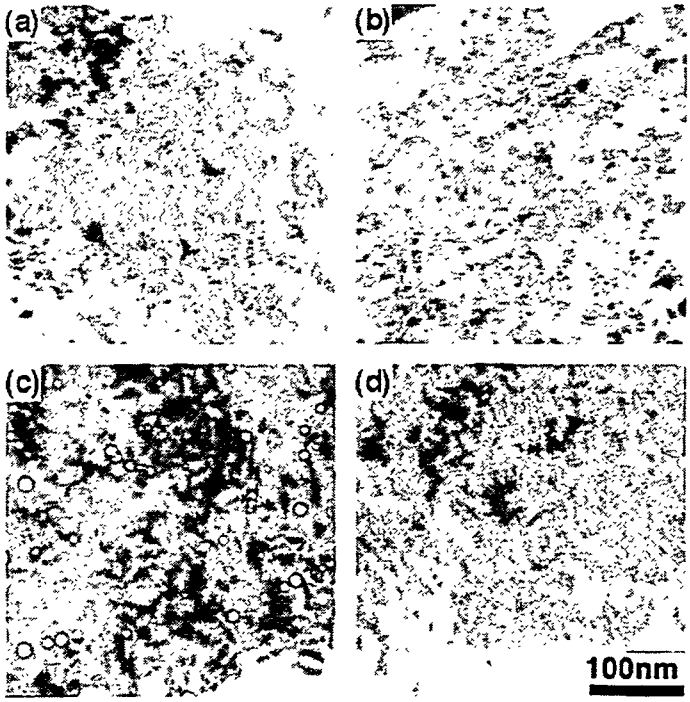

Figure 3 Microstructures of the cavities in HT9-std. (a), HT9-^{58}Ni (b), F82H-std. (c) and 8Cr-2WVTa-^{58}Ni (d) after irradiation at 400°C to 7.4 dpa.

FUTURE WORK

Further analysis of precipitates in the alloys will be carried out.

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