COMPARISON OF MICROSTRUCTURE BETWEEN NEUTRON-IRRADIATED REDUCED-ACTIVATION FERRITIC/MARTENSITIC STEELS, F82H-IEA, JLF-1 AND ORNL9CR—

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OBJECTIVE

To clarify the mechanisms of the difference in Charpy impact properties between F82H-IEA, JLF-1, and ORNL9Cr steels after irradiation, TEM microstructural analysis was performed.

SUMMARY

Transmission electron microscopy (TEM) specimens of F82H-IEA, F82H HT2, JLF-1, and ORNL9Cr steels were prepared from miniature Charpy specimens irradiated up to 5 dpa at 573K by using the Focused Ion Beam (FIB) technique in order to determine the mechanisms that cause the difference in Charpy impact properties. TEM microstructural analysis was performed with emphasis on dislocation structure and precipitate distribution. The TEM specimens indicated no significant difference on dislocation microstructures, such as dislocation loop size and density, in the steels. While precipitate's distribution of each steel was somewhat different in their size and density, larger precipitates were observed on prior austenite grain (PAG) boundaries and martensite packet boundaries of F82H-IEA and F82H HT2 compared to JLF-1 and ORNL9Cr. TEM analysis also suggested that ORNL9Cr had the finest grain structure, and F82H had a coarse grain structure. The microstructure of the deformed region of irradiated F82H-IEA contained dislocation channels. This suggests that dislocation channeling could be the dominant deformation mechanism in the RAFs, resulting in the loss of strain-hardening capacity.

PROGRESS AND STATUS

Introduction

Since ferritic/martensitic steels have several advantages based upon their resistance to void swelling, good thermal stress resistance, and well-established commercial production and fabrication technologies, reduced-activation ferritic/martensitic steels (RAFs) have been developed as candidate materials for structural applications in fusion energy systems. In a previous study, it was reported that ORNL9Cr-2WVTa and JLF-1 (Fe-9Cr-2W-V-Ta-N) steels showed smaller ductile-brittle transition temperature (DBTT) shifts compared to IEA-modified F82H (Fe-8Cr-2W-V-Ta) after neutron irradiation up to 5 dpa at 573K. This difference in DBTT shift could not be interpreted as an effect of irradiation hardening. To clarify the mechanisms of the difference in Charpy impact property between these steels, microstructure analyses by transmission electron microscopy (TEM) were performed.

Experimental Procedure

The materials used were IEA modified F82H with its standard heat treatment and an alternate heat treatment (HT2), JLF-1, and ORNL9Cr-2WVTa. The compositions and the heat treatments are given in Table 1. Miniature Charpy specimens of these steels were irradiated up to 5 dpa at 573K in HFIR RB-11J capsule with europium thermal neutron shields for neutron spectrum tailoring. TEM specimens were prepared from the miniature Charpy specimens by using the FIB processor (Hitach FB-2000A) with a microsampling system at Japan Atomic Energy Research Institute (JAERI). FIB fabrication can provide the optimum sample taken from a proper area of bulk specimen and less magnetic field samples to be handled just as nonmagnetic materials. The Low Energy Gun Milling (LEG) was carried out at JAERI for 4 all specimens to remove damage by fabrication. The FIBed samples were examined using a JEM-2000FX (LaB6) transmission electron microscope at ORNL.

Table 1 Chemical compositions of the steel used in this experiment

	C	Cr	W	V	Ta	Ti	N
F82H-IEA	0.11	7.7	2.00	0.16	0.02	0.01	0.008
JLF-1	0.1	8.9	1.95	0.20	0.09	0.002	0.023
ORNL9Cr	0.1	8.8	1.97	0.18	0.065	-	0.023

Heat treatment:	F82H-IEA	1313K/40min/AC + 1023K/1hr
	F82H HT2	NT + 1193K/1hr/AC + 1023K/1hr
	JLF-1	1323K/1hr/AC + 1053K/1hr
	ORNL9Cr	1323K/1hr/AC + 1023K/1hr

Results and Discussion

Before TEM examination of the irradiated steels, microstructures of unirradiated (normalized-and-tempered) F82H-IEA, F82H HT2, JLF-1, and ORNL9Cr were examined by exraction replica [1] and TEM in order to investigate grain size, distribution and chemical composition of precipitates. In all the steels, precipitates on prior austenite grain (PAG) boundaries were mainly $M_{23}C_6$; the average size in F82H-IEA, F82H HT2, JLF-1, and ORNL9Cr is 103, 106, 123, and 111 nm, respectively. Also, there were a few MX-type precipitates in F82H-IEA and F82H HT2, which were Ti-rich. A lot of fine MX precipitates without Ti were found in ORNL9Cr and JLF-1. Furthermore, F82H-IEA had large PAGs and martensite packets, the other steel's PAGs were relatively smaller than F82H-IEA.

Fig. 1 shows typical microstructures of F82H-IEA, F82H HT2, JLF-1, and ORNL9Cr irradiated up to 5 dpa at 573K using the diffraction condition: **B**=001, ***g***=110 and (***g***,***5g***). The TEM specimens indicated irradiation-induced dislocation loops with a high number density in all the steels, although there was no significant difference on dislocation microstructures, such as size and number density, between the steels. Also, the size of PAG and packets of the steels were not changed by the irradiation.

In all the steels, precipitates on PAG boundaries were mainly $M_{23}C_6$, and it seemed that irradiation-enhanced precipitation had occurred. Precipitate's distribution of each steel showed some difference in size; relatively larger precipitates were observed on PAG boundaries and packet boundaries of F82H-IEA and F82H HT2 compared to JLF-1 and ORNL9Cr. On the other hand, fine precipitates observed in the unirradiated specimens were not found in the irradiated JLF-1 and ORNL9Cr steels. The results of exraction residue and XRD experiments [1] suggested that the MX precipitates (probably TaC) disappeared after irradiation, and a similar phenomenon (dissolution of TaC) was reported in ion-irradiated Fe-0.2Ta-0.015C alloy [2]. Estimation of fracture stress with the modified Griffith equation [1] indicated a possibility that dissolution of Ta in MX precipitates could lead to an increase of the surface energy and the fracture stress, resulting in the low DBTT of the irradiated JLF-1 and ORNL9Cr.

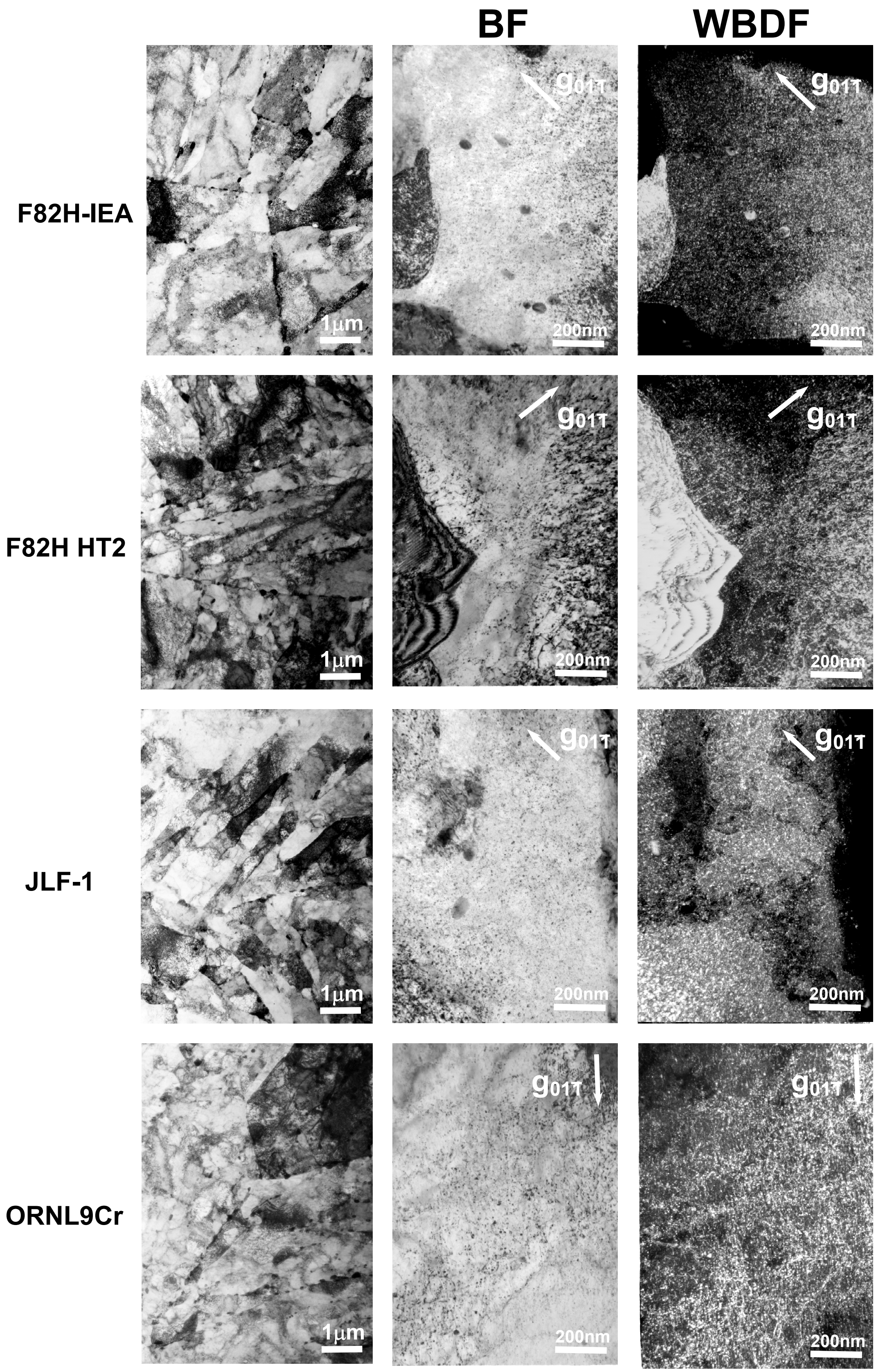

Fig. 1. Typical microstructures of F82H-IEA, F82H HT2, JLF-1, and ORNL9Cr irradiated up to 5 dpa at 573K using the diffraction condition: **B**=001, ***g***=110 and (***g***,***5g***).

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References

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