CHARPY IMPACT PROPERTIES OF REDUCED-ACTIVATION FERRITIC/MARTENSITIC STEELS IRRADIATED IN HFIR UP TO 20 DPA — H.Tanigawa (Japan Atomic Energy Research Institute), M.A. Sokolov (Oak Ridge National Laboratory), K. Shiba (JAERI), R.L. Klueh (ORNL)

OBJECTIVE

The objective of this work is to (1) analyze the results of Charpy impact tests on HFIR 11J-, 12J- JP25-irradiated CVN specimens, (2) investigate the DBTT shift saturation of F82H, (3) determine the validity of the TIG welding process, (4) investigate He and grain size effects.

SUMMARY

The effects of irradiation up to 20 dpa on the Charpy impact properties of reduced-activation ferritic/martensitic steels (RAFs) were investigated. The ductile-brittle transition temperature (DBTT) of F82H-IEA shifted up to around 50°C. TIG weldments of F82H showed a fairly small variation on their impact properties. A finer prior austenite grain size in F82H-IEA after a different heat treatment resulted in a 20°C lower DBTT compared to F82H-IEA after the standard heat treatment, and that effect was maintained even after irradiation. Helium effects were investigated utilizing Ni-doped F82H, but no obvious evidence of helium effects was obtained. ORNL9Cr-2WVTa and JLF-1 steels showed smaller DBTT shifts compared to F82H-IEA.

PROGRESS AND STATUS

Introduction

Reduced-activation ferritic/martensitic steel (RAF) is one of the candidate structural materials for a fusion power plant reactor. It is being investigated in the Japan Atomic Energy Research Institute (JAERI) and DOE collaboration program with the emphasis on F82H (Fe-8Cr-2W-VTa), which was developed by JAERI and NKK Corporation, Kawasaki, Japan. To validate the potential of RAFs as the structural material for fusion power plants, it must be ensured that the materials have adequate fracture toughness at the application temperature, including the welded joints. It is also important to establish the effect of the presence of gas atoms (hydrogen and helium) formed by transmutations induced by 14MeV neutron bombardment from the fusion reaction.

Previous irradiation test results after irradiation up to 11 dpa at temperatures below 400°C indicated that the shift of ductile-brittle transition temperature (DBTT) to a higher temperature depends on irradiation dose. This is important because 100°C is expected to be the lowest temperature of fusion blankets [1-3]. Current interest is to determine whether there is a saturation dose level or not, and to know the degradation level of toughness after saturation. Additionally, the effect of transmutation-formed helium on the mechanical properties, especially fracture toughness, is one of the most important issues that needs to be understood for expected power plant reactor application. In this study, the effects of irradiation up to 20 dpa on the Charpy impact properties of RAFs were investigated.

Experimental

The material used for this research was IEA-modified F82H (F82H-IEA), nominally Fe-7.5Cr-2W-0.15V-0.02Ta-0.1C. Base metal with two heat treatment variations (standard IEA heat treatment and another heat treatment designated HT2) and TIG weldments (weld metal and weld joint) of F82H were irradiated. Details of weld conditions were shown elsewhere [4]. F82H doped with 2%Ni (F82H+2Ni) was also irradiated to study the effect of helium produced from a two-step reaction involving ^{58}Ni and thermal neutrons, along with chemical effects of nickel itself. For the maximum dose of 20 dpa, 200 appm He were formed in the nickel-doped material. ORNL9Cr-2WVTa and JLF-1 steels were also irradiated for comparison. The details of the chemical compositions and heat treatments of these materials are listed in Table1 and Table2.

Table 1. Chemical compositions of RAFs (wt%)

	C	Cr	W	V	Ta	Ti	N	Ni
F82H- IEA :	0.11	7.7	2.00	0.16	0.02	0.01	0.008	-
F82H+2Ni :	0.1	7.9	1.99	0.19	0.06	0.005	0.004	1.9
9Cr-2WVTa:	0.1	8.8	1.97	0.18	0.065	<0.01	0.023	-
JLF-1 :	0.1	8.9	1.95	0.20	0.09	0.002	0.0215	-

Table 2. Heat treatment conditions

F82H-IEA	: 1040°C/40min/AC + 750°C/1hr
F82H HT2	: (F82H-IEA) + 920°C/1hr/AC + 750°C/1hr
F82H +2Ni	: 1040°C/30min/AC + 750°C/1hr
9Cr-2WVTa	: 1050°C/1hr/AC + 750°C/1hr
JLF-1	: 1050°C/1hr/AC + 780°C/1hr

Miniature Charpy specimens (3.3 x 3.3 x 25.4 mm with 0.51 mm V-notch) were used for the impact tests, and SS-3 tensile specimens (gage section : 7.62 x 0.76 x 1.5 mm) were used to evaluate the relation between hardening and DBTT shift. Irradiation was performed in the Oak Ridge National Laboratory (ORNL) High Flux Isotope Reactor (HFIR). Two capsules (RB-11J and RB-12J) were irradiated to ≅5 dpa at 300°C and 500°C in the boron reflector position, and another capsule (JP25) was irradiated in the target position to ≅20 dpa at 380°C and 500°C. The two RB capsules contained a europium thermal neutron shield for neutron spectrum tailoring.

Charpy impact tests were carried out with an instrumented Charpy impact machine in the Irradiated Materials Examination and Testing (IMET) hot cell facility at ORNL. Testing temperatures ranged from -20°C to 100°C to obtain DBTT and upper-shelf energy (USE) values. SEM observations were made on selected tested specimens. Tensile tests were carried out at room temperature with a strain rate of 0.01 /s.

Table 3. Summary of Charpy impact properties and tensile results.

Material	*Nominal irradiation condition* Dose, dpa	Temp., °C	*Mid-Trans. DBTT, °C*	*Δ DBTT, °C*	*USE, J*	*σ_y, MPa*	*Δ σ_y, MPa*
F82H-IEA	-	-	-84	-	11.58	528	-
	5	300	23	107	10.13	898	370
		500	-54	30	11.56	527	-1
	20	380	50	134	8.7	-	-
		500	-46	38	12.03	-	-
F82H (HT#2)	-	-	-101	-	14.09	501	-
	5	300	3	104	11.76	865	364
		500	-92	9	12.0	485	-16
	20	380	33	133	8.31	-	-
F82H + 2Ni	-	-	-103	-	9.11	651	-
	5	300	137	240	4.09	1281	630
		500	-82	11	10.36	613	-44
	20	380	11	114	5.57	-	-
		500	-77	26	11.56	-	-
Weld Metal	-	-	-83	-	10.88	637	-
	5	300	50	133	9.11	963	326
		500	-37	46	12.74	-	-
	20	380	33	115	7.71	-	-
Weld Joint	-	-	-110	-	10.73	-	-
	5	300	22	132	10.47	-	-
9Cr-2WVTa	-	-	-94	-	10.96	577	-
	5	300	-31	63	9.5	1040	463
		500	-78	16	10.47	569	-8
JLF-1	-	-	-85	-	9.9	525	-
	5	300	-37	48	10.48	839	314
		500	-66	19	12.04	-	-

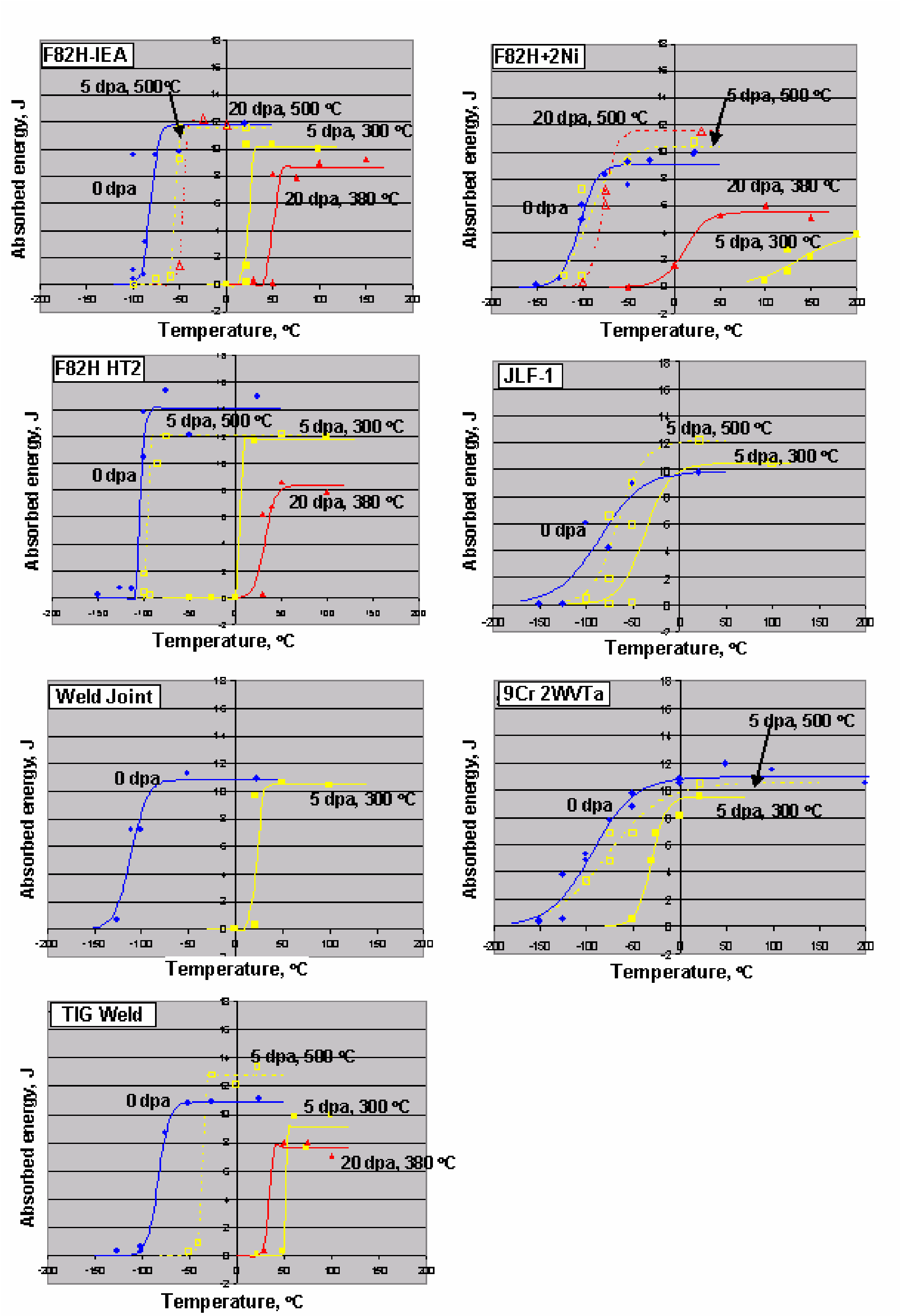

Fig. 1. Charpy curves obtained in this research.

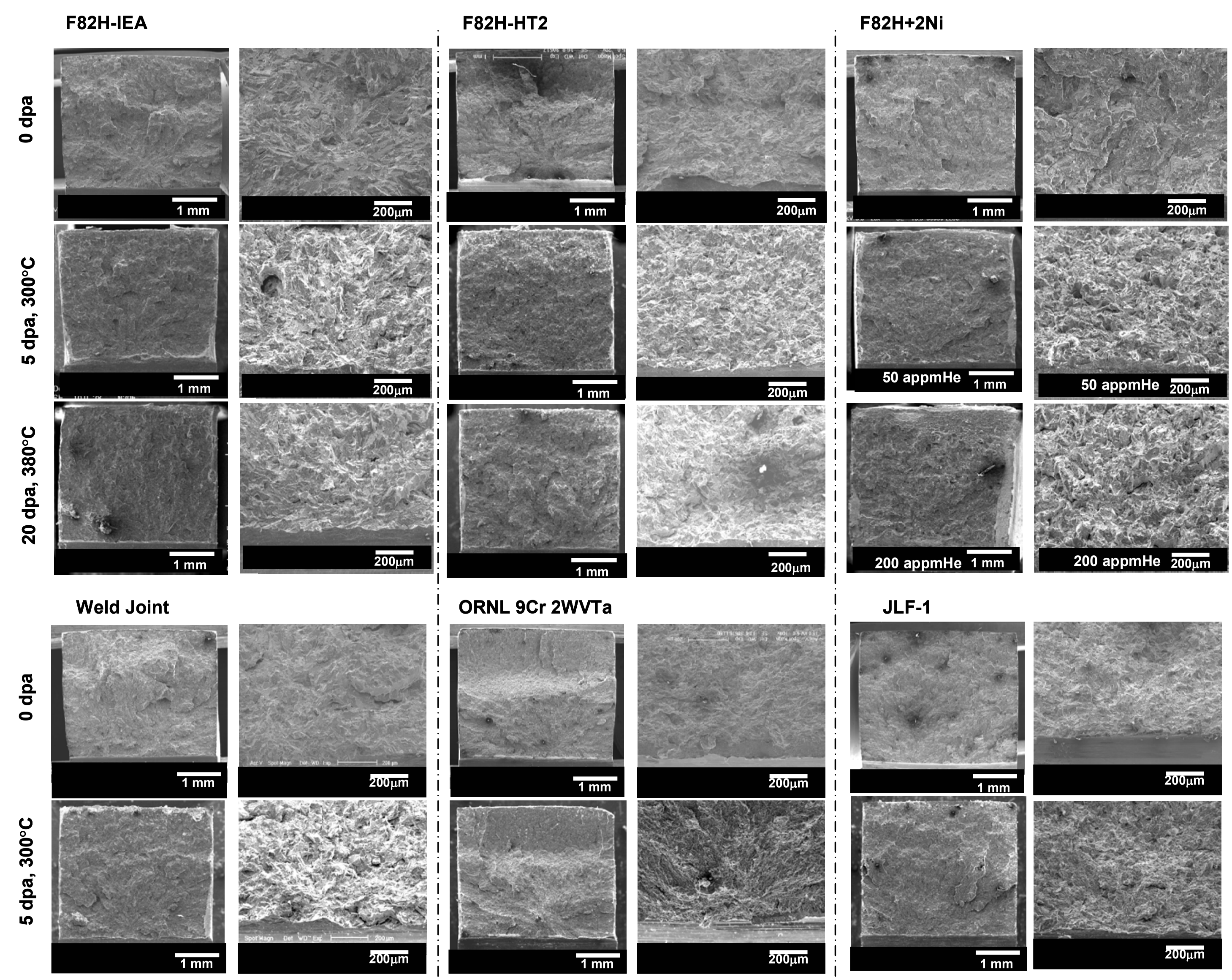

Fig. 2 Fracture surfaces of Charpy impact-tested specimens. Right side pictures of each material/ conditions are the magnified images of fracture initiation points

Results and discussion

Results for the Charpy tests and tensile tests are given in Table 1. Charpy curves and SEM observations of fracture surfaces obtained in this research are shown in Fig. 2 and Fig. 3, respectively. The DBTT was obtained at half the USE value. The DBTT of each of the steels was shifted to a higher temperature after irradiation.

Irradiation dose dependence of the shift in DBTT (ΔDBTT) of F82H-IEA is summarized in Fig. 3. Irradiation up to 5 dpa at 300°C shifted the DBTT up to around room temperature, and there was no obvious indication which suggests a DBTT shift saturation. On the other hand, the DBTT was not further shifted by an increase in irradiation from 11 dpa [3] to 20 dpa at 380°C. This result indicates the ΔDBTT induced by irradiation around 380°C was saturated at 11 dpa.

The DBTT and USE of the weldments before and after irradiation at 300°C up to 5 dpa are summarized in Fig. 4. Base metal (F82H-IEA), weld metal (TIG weld) and weld joint material exhibited about the same shifts of DBTT after irradiation under similar conditions. The USE for all irradiated weldments exhibited only a small drop from the unirradiated level. From these results, it was concluded that TIG weldments have acceptable impact properties, even after the irradiation.

The effects of prior austenite grain size on DBTT shift were investigated by comparing F82H-IEA (ASTM grain size 3.3) to F82H-HT2 (ASTM grain size 6.5). The fine grain structure in F82H-HT2 was obtained by renormalizing F82H-IEA using a lower austenitization temperature (920°C) (see Table 2). The results show that the DBTT of both unirradiated and irradiated HT2 are slightly (~20°C) lower than for F82H-IEA, and the finer-grain F82H-HT2 has a higher USE than F82H-IEA. (see Fig. 5). From these results, it is concluded that F82H-HT2 benefited from the fine grain size after irradiation compared to F82H-IEA steel.

Helium effects on Charpy impact properties were investigated with the Ni-doped F82H. A large DBTT shift and drop of USE were obtained with F82H+2Ni irradiated up to 5 dpa at 300°C (see Fig. 1) . The DBTT of the F82H+2Ni irradiated up to 20 dpa at 380°C is lower than that irradiated up to 5 dpa at 300°C, although 200 appm helium was

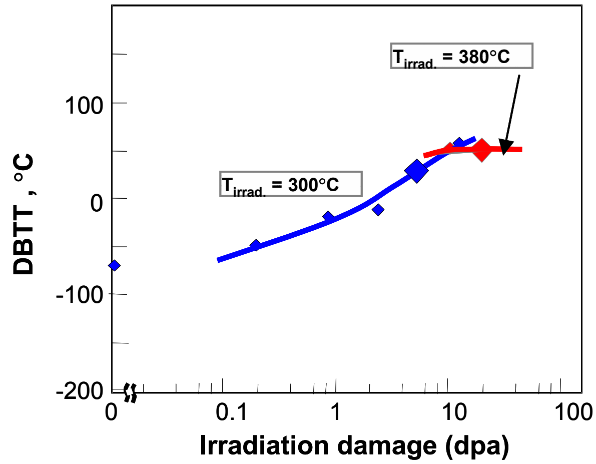

Fig. 3. Irradiation damage dependence of the DBTT of F82H-IEA irradiated at 300°C and 380°C. Data points indicated by small squares were reported elsewhere [3, 5].

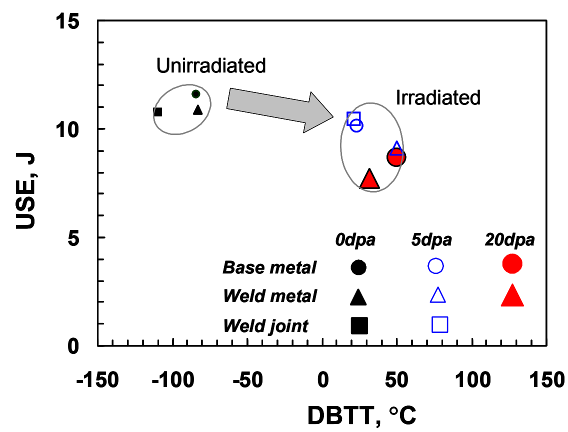

Fig. 4. DBTT and USE changes of base metal, weld metal, and weld joint caused by irradiation.

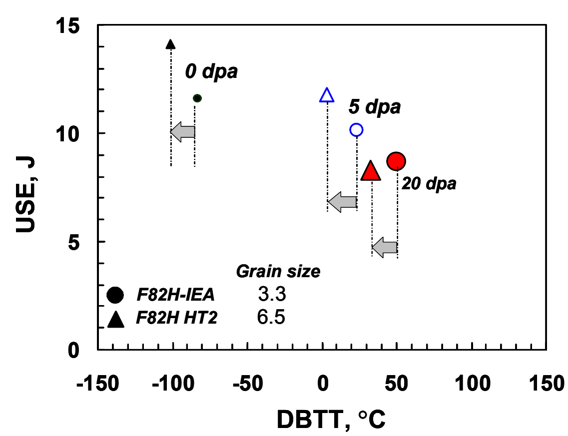

Fig. 5, Effect of prior austenite grain size on Charpy impact properties.

produced for the former case. This could be explained in terms of irradiation temperature. Fracture surfaces were observed for each irradiation condition on specimens that fractured in a brittle mode (~ 0.1J) on the lower shelf (see Fig.3). All specimens showed typical brittle cleavage fracture surfaces, and there was no evidence of intergranular fracture. From these results, it was concluded that helium up to 200 appm did not affect the fracture mode.

Correlation between ΔDBTT and yield stress increase ($\Delta\sigma_y$) is shown in Fig. 6 for F82H-IEA, F82H-HT2, F82H+2Ni, 9Cr-2WVTa and JLF-1. The three F82H vaiations follow the same trend. Ni-doped specimens are also on the same trend. From this, the large ΔDBTT of Ni-doped F82H could be explained as the effect of radiation hardening, just as the other steels. The values for 9Cr-2WVTa and JLF-1 are slightly lower than the main trend. The reason for this difference between F82H and the two 9Cr steels was not clarified in this study, and this will be investigated further in the future.

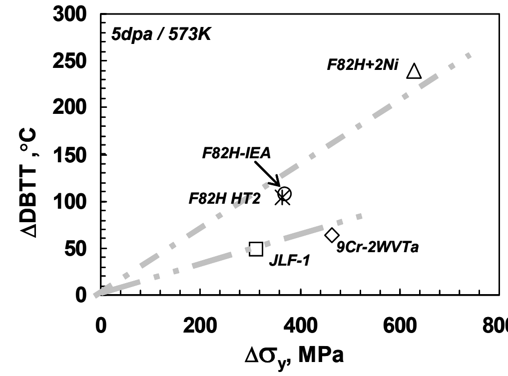

Fig. 6 Relation between DBTT shift and yield stress increase.

Charpy impact properties changes for the specimens irradiated at 500°C are summarized on Fig. 7. The weld metal shows a large ΔDBTT and USE increase compared to those of the base metal (F82H-IEA). This indicates that there could be a better post-weld heat treatment that would make the weld metal much more like the base metal than the current condition. Ni-doped F82H showed an increase in USE which is not understood in light of the hardening. JLF-1 also showed an increase in USE, and this can be explained as the result of the martensitic lath structure recovery, which appears in JLF-1 at higher irradiation temperatures [6].

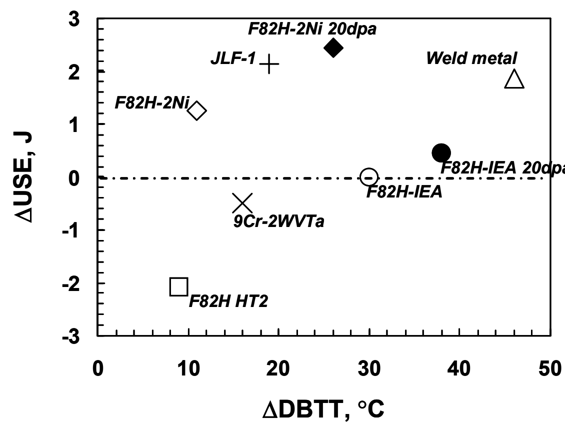

Fig. 7 Charpy impact properties changes of RAFs irradiated at 500°C up to 5 and 20 dpa.

SUMMARY AND CONCLUSIONS

Reduced-activation ferritic/martensitic steels (RAFs) are being investigated in the JAERI/DOE collaboration program with the emphasis on F82H (Fe-8Cr-2W-VTa) to validate the potential of RAFs as the structural material for fusion power plants. The effects of irradiation up to 20 dpa on the impact properties of RAFs were investigated in this study. The following is a summary of the important conclusions:

1. Irradiation of F82H-IEA up to 5 dpa at 300°C shifted the DBTT up to room temperature.
2. No obvious results were obtained which suggested a DBTT shift saturation after irradiation at 300°C to 5 dpa.
3. TIG weldments have acceptable impact properties even after the irradiation.
4. The use of a lower austentization temperature to produced a finer grain size improved the properties of F82H-IEA.
5. All Ni-doped F82H specimens showed typical brittle fracture surfaces, and there was no evidence of intergranular fracture.
6. The large ΔDBTT of Ni-doped F82H could be explained as the effect of radiation hardening, just as

the other steels.

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