MICROSTRUCTURAL OBSERVATION OF HFIR-IRRADIATED AUSTENITIC STAINLESS STEELS INCLUDING WELDS FROM JP9-16 --- T. Sawai, K. Shiba, A. Hishinuma [Japan Atomic Energy Research Institute)

SUMMARY

Austenitic stainless steels, including specimens taken from various electron beam (EB) welds, have been irradiated in HFIR Phase II capsules, JP 9-16. Fifteen specimens irradiated at 300, 400, and 500°C up to 17 dpa are so far examined by a transmission electron microscope (TEM). In 300°C irradiation, cavities were smaller than 2 nm and different specimens showed little difference in cavity microstructure. At 400°C, cavities were larger but still very small (<8 nm). At 500°C, cavity size reached 30 nm in weld metal specimens of JPCA, while cold worked JPCA contained only small (<5 nm) cavities. Inhomogeneous microstructural evolution was observed in weld-metal specimens irradiated at 500°C.

PROGRESS AND STATUS

To evaluate the performance of weld joint of austenitic stainless steels is one of the major objectives of HFIR Phase II irradiation project in JAERI-ORNL collaborative program. Studies on the microstructural evolution of irradiated weld are extremely limited although the complex blanket structure of fusion reactor requires inevitable welding. High voltage electron microscope (HVEM) irradiation has shown appreciable increase of swelling in welded austenitic stainless steels [1]. Swelling was especially high at the weld metal due to segregation. The objective of this study is to reveal the microstructural evolution of welded austenitic stainless steels irradiated by HFIR neutrons.

Table 1. TEM specimens examined.

JP10, position 4. 400 °C 16.7dpa

ID	description	Negative #
AH25	316F SA BM	J19197-J19215 J19413-J19441
PK03	JPCA SA TIG HAZ	J19216-J19253
AA25	316F SA EB WM	J19254-J19279
PJ16	JPCA SA TIG WM	J19280-J19309
AE15	316F SA EB sHAZ	J19310-J19342 J19385-J19412

JP11, position 6, 500 °C 17.3dpa

ID	description	Negative #
BN38	JPCA CW BM	J19480-J19519
BL21	JPCA CW EB sHAZ	J19520-19544
HJ22	JPCA SA 10Ti-EB WM	J19546-J19645
BM09	JPCA CW EB J*	J19646-19725

* TEM foil was obtained at WM

JP10, position 6, 400 °C 17.3dpa

ID	description	Negative #
BN25	JPCA CW BM	J19774-J19848
BL13	JPCA CW EB sHAZ	J19849-J19892
BM06	JPCA CW EB J**	J19893-J19940

** TEM foil was obtained at WM

JP10, position 8 300 °C 16.7dpa

ID	description	Negative #
AH33	316F SA BM	J19991-J20040***
PJ19	JPCA SA TIG WM	J20041-J20106***
AA33	316F SA EB WM	J20128-J20166

*** Numbers on negatives read J1????, not J2????.

abbreviations;
- SA : solution annealed
- CW : cold worked
- EB : electron beam (weld)
- TIG : tungsten inert gas (weld)
- BM : base metal
- WM : weld metal
- HAZ : heat affected zone
- sHAZ : simulated HAZ
- J : joint (fusion line at the disk center)

EXPERIMENTAL

Two kinds of austenitic stainless steels, JPCA and 316F, were welded by electron beam (EB) welding and tungsten inert gas (TIG) welding. TEM specimens obtained from these welds were loaded in capsules JP9 through 16. Details of specimens were summarized elsewhere [2]. Fifteen TEM specimens from two capsules (four container tubes) were examined as the first batch of these experiments. Table 1 shows the list of these specimens. Damage level given in Table 1 is calculated values for type 316 steel (13Ni, 18Cr) [3]. The analysis of obtained micrographs is now going on. Results so far obtained are as follows.

RESULTS AND DISCUSSIONS

300 °C irradiation

Only three specimens at this irradiation condition were examined. They are 316F BM (AH33), 316F SA EB WM(AA33), and JPCA SA TIG WM (PJ19). Differences in microstructural evolution of these specimens are very small. Cavities are very fine (up to 2nm) and the size of Frank loops is less than 25 nm. In weld metal specimens (AA33, PJ19), cellular structure due to solidification was observed but the microstructural evolution at the cell boundary or cell center region showed no difference. Some microstructural features recognized as tiny black dots in a bright field image showed triangles in a weak beam dark field image with B = <110>. This suggests these features are stacking fault tetrahedra (SFT).

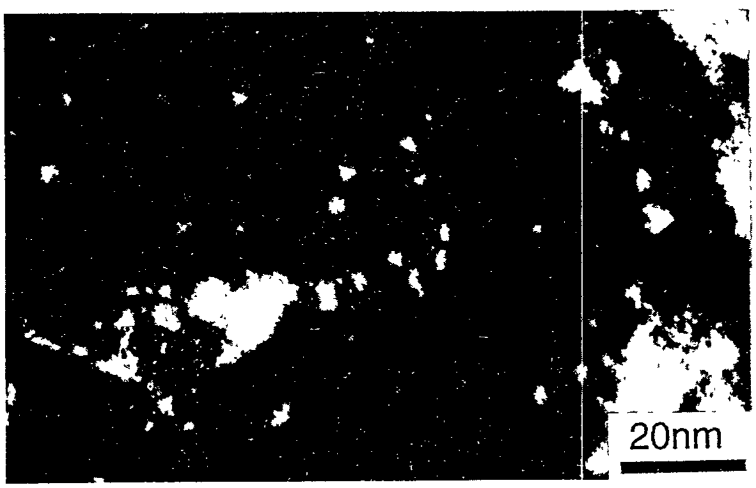

Fig. 1. Stacking fault tetrahedra observed in a JPCA SA TIG WM specimen irradiated in HFIR at 300°C up to 16.9 dpa. This micrograph was taken with B = <110>.

400°C irradiation

Eight specimens were examined at this irradiation condition. For detail, see Table 1. Larger cavities were observed at this irradiation condition compared to that of 300°C. Cavities in 316F specimens are almost the same size (4 nm), but JPCA specimen showed wider size distribution of cavities up to 8nm. This coincides with the results of immersion densitometry where 316F showed less swelling than JPCA [4]. Frank loops were also larger than those of 300°C irradiation. Their size is up to 40 nm. SFTs were also observed. Their size is up to 4 nm (almost similar to 300°C irradiation), and the number density, which is very hard to measure, seems to be less than that of 300°C irradiation.

In specimens obtained from weld metal (AA25, BM06, PJ16), cellular structure due to solidification was observed but the microstructural evolution at the cell boundary or cell core area showed no difference.

500°C irradiation

Only JPCA specimens were observed in this irradiation condition. A cold worked specimen (BN38) showed a good swelling resistance. Its cavity size is less than 5 nm. On the other hand, heat treated cold worked specimen (CW sHAZ, BL21) showed larger swelling. The cavity size is up to 20 nm. The CW EB J specimen (BM09) had its electron transparent foil at the weld metal. This specimen can be regarded as the weld metal specimen of JPCA EB welding. Another weld metal specimen observed is obtained from Ti-foil-insert welding [5]. The Ti concentration at the weld metal is 0.28 wt% [2]. In both weld metal specimens, cellular structure was observed and the microstructural evolution was quite different at the cell boundary and at the cell center region. At the cell boundary, size of cavities are up to 5 nm, showing good swelling resistance. Cavities at the cell center region included much larger ones. The cavity size reached 30 nm and showed bimodal distribution. As for Frank loops, the size and number density were larger at the cell center region than at the cell boundary.

In HFIR phase I experiments of JAERI-ORNL collaboration, the difference in the swelling resistance between solution annealed condition and cold worked condition or 316R and JPCA was clearly observed only at 500°C and higher temperatures [6-8]. In present experiment, different cavity microstructure in various specimens was clearly observed only at 500°C, either. Cavities observed in specimens irradiated at 300 and 400°C were helium bubbles.

Inhomogeneous cavity formation in weld metal was first reported by a HVEM irradiation experiment [1]. A typical cellular microstructure of weld metal is shown in Fig. 2 [1]. HVEM irradiation of weld metal of Type 316 stainless steel containing 0.08 Ti led inhomogeneous cavity formation and growth (Fig. 3 [1]). Present results of weld metals irradiated at 500°C are also shown in Fig. 4. These micrographs were quantified and the results are shown in Fig. 5.

Fig. 2. A typical cellular structure of weld metal [1]. This specimen was taken from EB-welded JPCA.

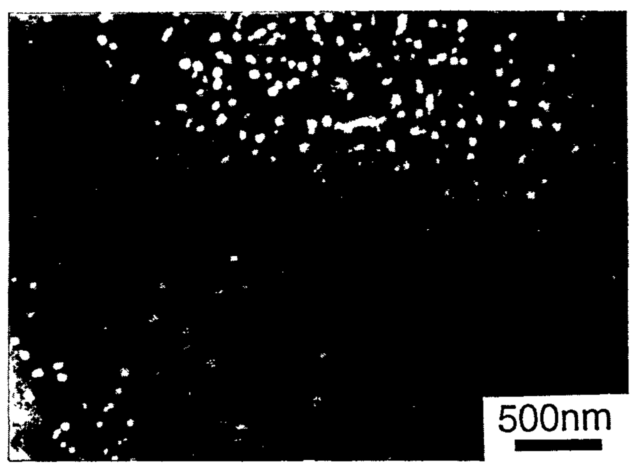

Fig. 3. Inhomogeneous cavity formation and growth in HVEM-irradiated weld metal [1]. This specimen was taken from EB-welded Type 316 stainless steel containing 0.08 Ti.

As shown in Fig. 3, cavity number density is much smaller at the cell boundary than at the cell center region in HVEM-irradiated weld metal. Enriched Ti at the cell boundary reduced the number density of cavities by trapping oxygen and/or nitrogen which will help the cavity nucleation. Cavity growth is also suppressed at the cell boundary. Enriched Ti also reduces the dislocation bias and, therefore, the supply of excess vacancy. In HFIR irradiation, the swelling is larger at the cell center region than at the cell boundary (Fig. 4 and Fig. 5). This result is similar to that of HVEM irradiation. The cavity number density is, however, much larger at the cell boundary than at the cell center region. Enough helium produced in HFIR

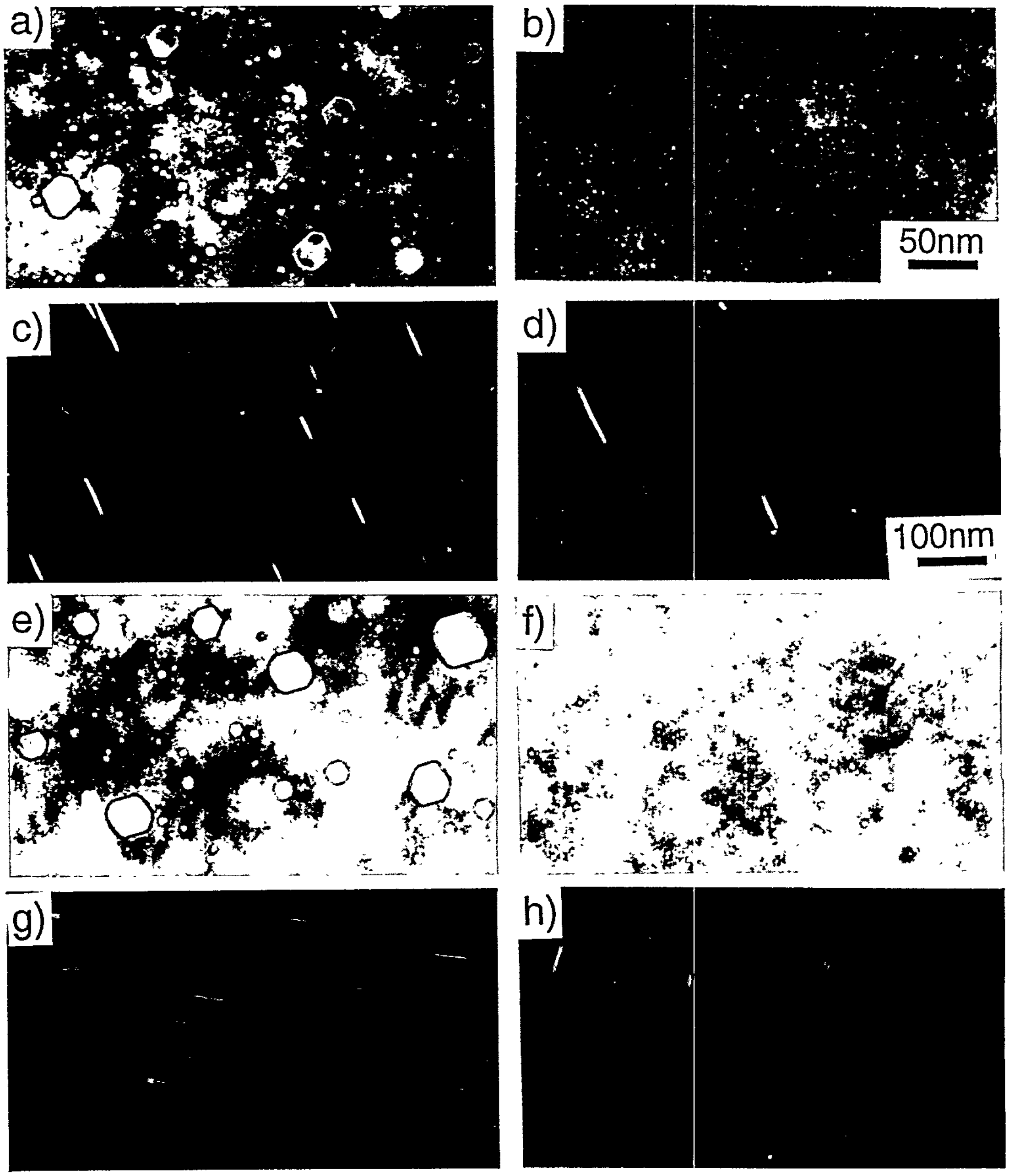

Fig. 4. Microstructure of two JPCA weld metal specimens irradiated at 500°C. Specimens are BM09, EB-welding [(a), (b), (c), (d)], and HJ22, 10micron-Ti-foil insert EB welding [(e), (f), (g), (h)]. Cavities are shown in (a), (b), (e), (f) and Frank loop in (c), (d), (g), and (h). Micrographs were taken at cell center region [(a), (c), (e), (g)], and at cell boundary [(b), (d), (f), (h)].

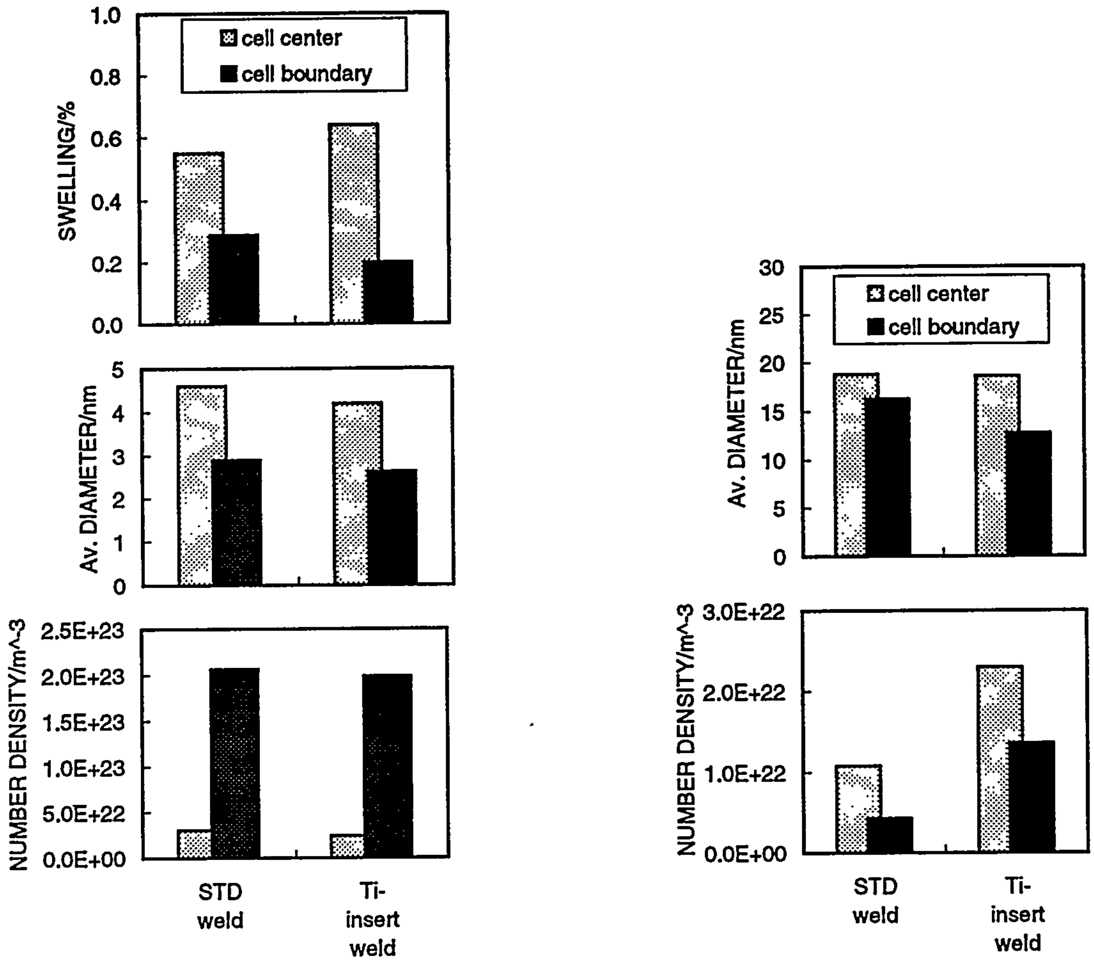

Fig. 5 Cavity and Frank loop data of two JPCA weld metal specimens irradiated at 500°C shown in Fig. 4.

irradiation enhances cavity nucleation. Present results on cavity microstructure at cell boundary and cell center region can be compared with that of 316R and JPCA base metals irradiated in HFIR Phase I capsules. Swelling is 0.25 and 1.09% for JPCA and 316R irradiated at 500°C to 34 dpa in HFIR Phase I capsules. Cavity number density is 1.3×10^{23} and 8.9×10^{21} m^{-3}, respectively. More swelling-resistant JPCA showed higher cavity number density. In HFIR neutron irradiation, swelling is suppressed by suppressing cavity growth, rather than suppressing cavity number density. Although the detailed microstructural evolution is thus different, swelling is enhanced at the cell center region both in HVEM irradiation and HFIR neutron irradiation.

In case of HFIR 500°C irradiation, solution annealed JPCA contained cavities up to 30 nm at 34 dpa [5]. Present results show that the weld metal specimens of standard and It-insert EB weld of JPCA contained cavities up to 30 nm at cell center region only after 17.3 dpa. This suggests the degradation of swelling resistance in austenitic stainless steel by welding. Present results also show that introduced titanium by Ti-insert EB welding could not prevent this degradation.

FUTURE WORK

Quantification of obtained micrographs will be continued.

REFERENCES

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