EXAMINATION OF POSTIRRADIATION DEFORMATION MICROSTRUCTURES IN F82H –

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OBJECTIVE

The objective of this effort is to provide further understanding of postirradiation deformation mechanisms controlling in ferritic/martensitic steels.

SUMMARY

The deformed microstructures of irradiated F82H uniaxial tensile specimens have been examined following irradiation in the High Flux Reactor (HFR) to 2.6 dpa at 327ºC in order to identify controlling mechanisms. Deformation following irradiation is found to occur in poorly defined channels, causing formation of discrete steps at surfaces, similar to that in unirradiated steel. Deformation is by motion of individual $\frac{a}{2}$<111> dislocations.

PROGRESS AND STATUS

Introduction

In a previous report on post-irradiation deformation behavior in ferritic/martensitic steels, results were obtained for an Fe-9Cr binary alloy irradiated in the FFTF at 370 and 400ºC to 10 and 40 dpa, respectively.[1] Behavior was compared to that in the unirradiated control material. It was found in both cases that deformation following irradiation occurred in poorly defined channels, causing formation of discrete steps at surfaces and delineated by nonuniformly distributed highly elongated voids. Deformation was by motion of $\frac{a}{2}$<111> dislocations, which interacted with and decomposed irradiation-induced a<100> loops. The structure formed after extensive deformation consists of highly complex cell walls and moderate densities of individual slip dislocations. In comparison, behavior for unirradiated samples gave surface steps that were poorly delineated and dislocation tangles with no obvious evidence of channeling.

The present effort is intended to extend those results to more complex steels. The work is based on F82H miniature tensile specimens recently irradiated in HFR in Petten, The Netherlands.

Experimental Procedure

Miniature sheet tensile specimens of F82H with nominal gauge dimensions of 5.1 mm x 0.25 mm x 1.0 mm were irradiated in the HFR up to a calculated dose level of ~2.6 dpa, and were tested to provide understanding of postirradiation deformation response in reduced activation steels.[2] Composition details are provided in Table 1.

Table 1. Chemical composition of F82H heat 9741.

C	Si	Mn	P	S	Cr	Ni	Mo	N
0.09	0.11	0.16	0.002	0.002	7.71	0.02	0.003	0.006
Cu	Co	Ta	B	Ti	Nb	V	Al	W
0.01	0.005	0.02	0.0002	0.01	0.0001	0.16	0.003	1.95

Irradiation details are as follows: irradiation vehicle: CHARIOT-2, a basket-type sample holder; target dpa: 2.5; actual dpa: 2.57; Thermal fluence; 1.53 dpa; Fast Fluence: 1.85 x10^{25} n/m^2;

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Target temperature: 300°C; Actual temperature estimated: 320-335°C; for 150 full power days ending March, 1997. (TEM disks were also included and underwent the following irradiation details: actual dpa: 2.84; Thermal fluence: 1.77 dpa; Fast Fluence: 2.05 x10^{25}n/m^2; Target temperature:300°C; Actual temperature estimated: 324-340 °C.)

Flat surfaces of sheet tensile specimens were mechanically polished to Linde 600 grit and then deformed at room temperature either to failure on the first test or to about 3% for the remaining specimens. Testing details are provided in Table 2 with elongation estimated from test traces. However, the test trace for specimen II was unusual, probably a result of slipping in the grips, and the test trace was so interpreted.

Table 2. Test Details for Deformed Tensile Specimens.

Specimen ID	Condition (°C)	Yield (MPa)	Max. load (MPa)	Elongation (%)
I	2.57 dpa at 327	626	653	0.6 UE, 5.8 TE
II	"	621	637	0.4 UE, 4?
III	"	609	634	0.6 UE, 2.8

UE: uniform elongation, TE: total elongation.

Following deformation, specimens were examined by SEM to identify regions that were deformed. Disks 1 mm in diameter were then punched from promising areas so that the edge of the specimen was retained on one side to allow determination of the stress axis. Each disk was then mounted in a 3 mm stainless steel disk using recently developed procedures [3] and prepared using normal polishing procedures. Microscopy was performed on a JEOL 1200EX transmission electron microscope operating at 120 KeV and using a double tilting ±45° goniometer stage. Imaging included procedures for identifying each of the a<100> and $\frac{a}{2}$<111> Burgers vectors in a field of view.[4] All micrographs have been digitized and some stereo images were prepared as anaglyphs, available on request.

Results

Surface Features

SEM revealed that surfaces of the irradiated specimens had developed poorly defined steps. The vertical surfaces of these steps were not flat, but instead showed fine slip traces. Examples are provided in Figures 1 and 2. Figure 1, containing montages at low magnification, compares the specimen taken to fracture (# I) with two specimens deformed to about half the strain to failure (#'s II & III). Areas in specimens II and III that show deformation are marked with arrows. From this figure, it is apparent that deformation is very localized and appears to emanate from an edge notch, in both cases. Figure 2 shows examples of specimen surfaces at higher magnifications with examples of unirradiated and irradiated Fe-9Cr for comparison. From Figure 2, it is apparent that irradiated F82H is behaving like unirradiated Fe-9Cr.

Microstructural Examination

The microstructure found in all irradiated specimens of F82H on a coarse scale was typical of martensitic steels. Lath boundaries were decorated with $M_{23}C_6$ carbides. Effects of irradiation and postirradiation deformation are on a finer scale than lath boundary dimensions. Examples of the microstructure at low magnification are provided in Figure 3. Specimen IA is shown on the left and IIA in the center and on the right. Careful examination reveals some differences; IA contains significantly less dislocation structure within martensite laths than does IIA.

The dislocation structure in specimen IA is shown in greater detail in Figure 4. The same area in bright and dark field contrast is shown for three different imaging conditions. From this figure, it is apparent that most of the structure is in the vicinity of the lath sub-grain boundaries. However,

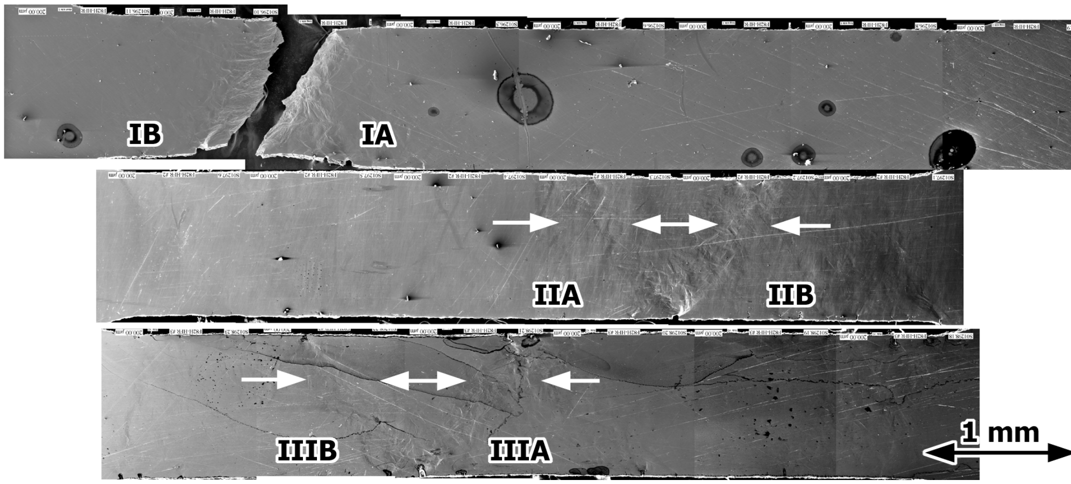

Figure 1. Low magnification examples of deformed F82H tensile specimens. Labels correspond to descriptions in the text.

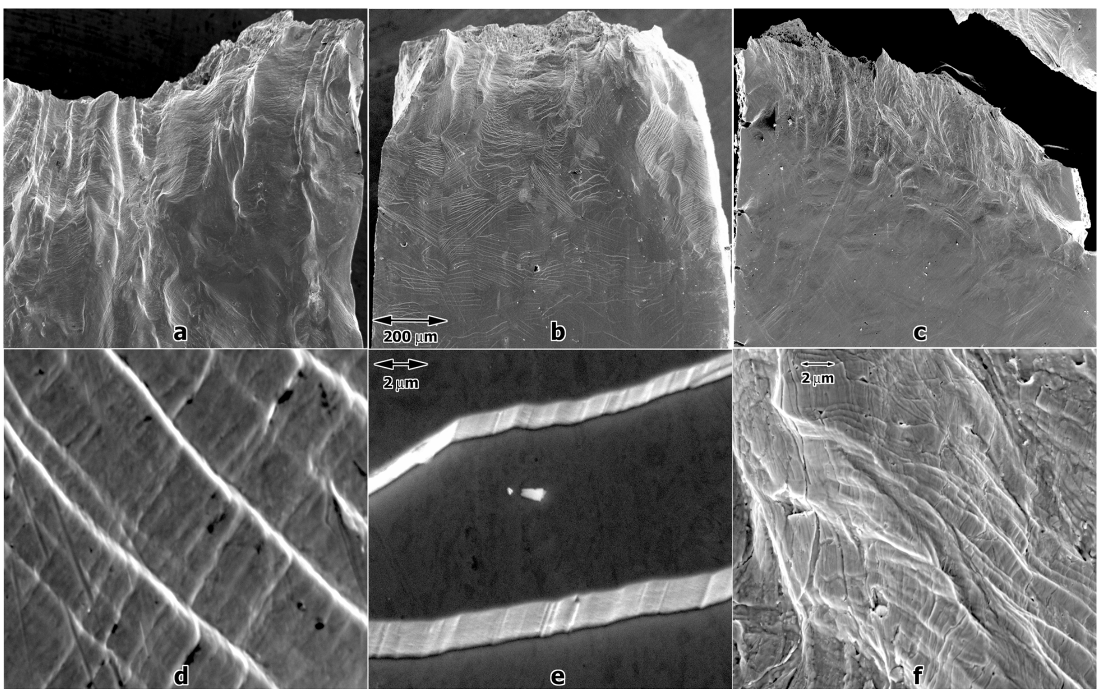

Figure 2. Higher magnification examples of the fracture surfaces and slip steps, with the unirradiated Fe-9Cr condition on the left, irradiated Fe-9Cr in the center and irradiated F82H on the right.

although it is not clear with bright field imaging, the boundary regions are decorated with fine structure, similar to loop structures that can be nucleated during irradiation near dislocations present prior to irradiation. Therefore, it is likely that this structure represents undeformed material. Apparently deformation only occurred less than about 0.5 mm from the failure site, and preparation of a thinned region 1 mm in diameter near the failure site therefore did not show deformation.

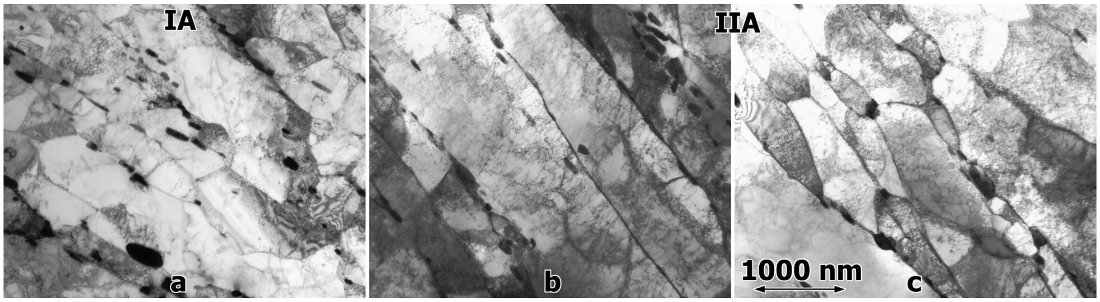

Figure 3. Martensite lath structure in specimens IA and IIA

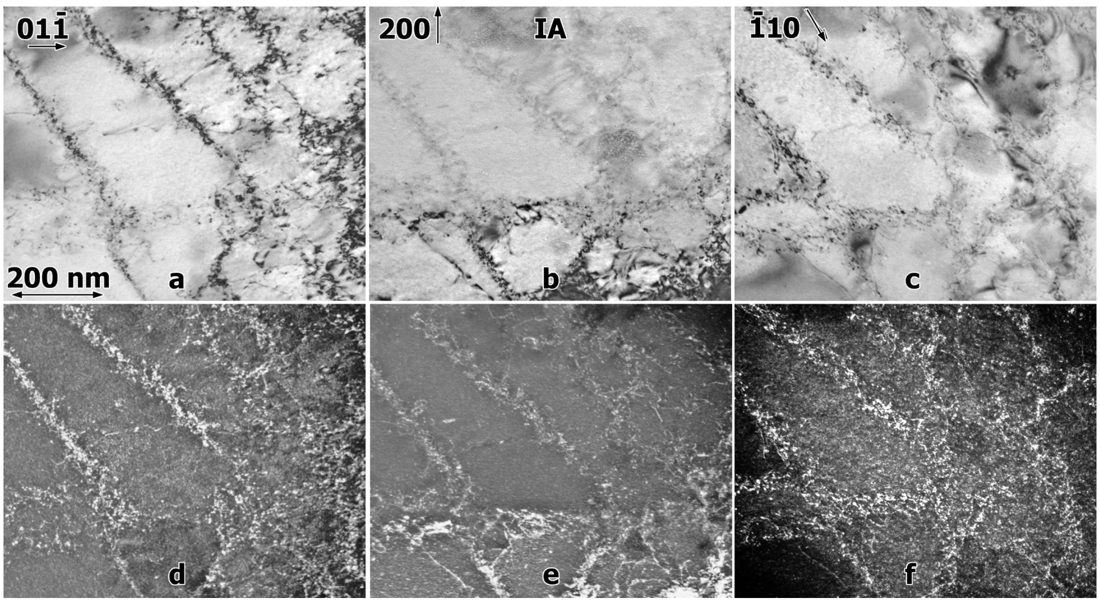

Figure 4. Microstructures in apparently undeformed regions of specimen IA shown in bright field a) to c) and dark field d) to f) contrast.

Figures 5 and 6 show dislocation structure in specimen II. An area in specimen IIA is shown in bright and dark field contrast for three different imaging conditions. Two significant differences can be identified in comparison to Figure 4. Many more individual dislocation lines are present between lath boundaries and the density of fine structure near lath boundaries appears to have been reduced. Figure 6 has been prepared to show two further regions in dark field contrast, one in specimen IIA and the other in specimen IIB.

<u>Discussion</u>

Postirradiation microstructural examination has shown that deformation in F82H to 2.7 dpa at 327ºC does not occur by channel deformation. Effects of irradiation are demonstrated. Fine structure typical of small dislocation loops has formed near dislocations in subgrain boundaries, and this may explain the increase in hardening observed. Companion specimens in the Chariot experiments have shown that unirradiated F82H gives ~540 MPa for the unirradiated condition yield strength, 610-660 MPa following irradiation to ~2.7 dpa (in agreement with the present results) and ~820 MPa following irradiation to doses of 5 dpa and above.[4] Therefore, it can be suggested that hardening is at least in part due to development of small loops in the vicinity of dislocations present prior to irradiation. For example, if the loops were of type a<100>, glide dislocations could react with the loop according to the relation:

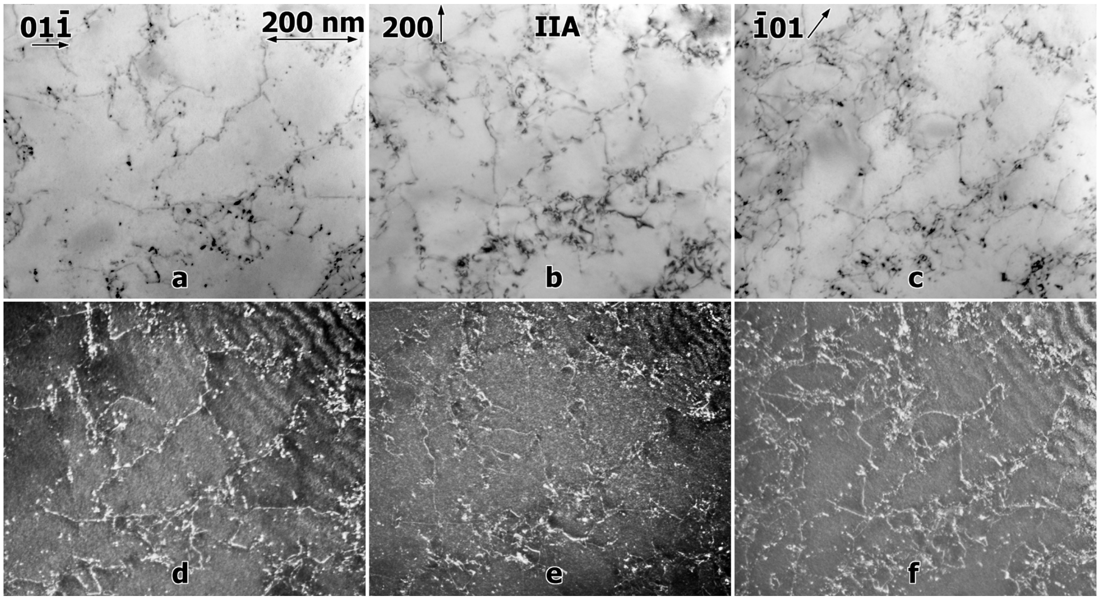

Figure 5. Microstructures in a deformed region of specimen IIA shown in bright field a) to c) and dark field d) to f) contrast.

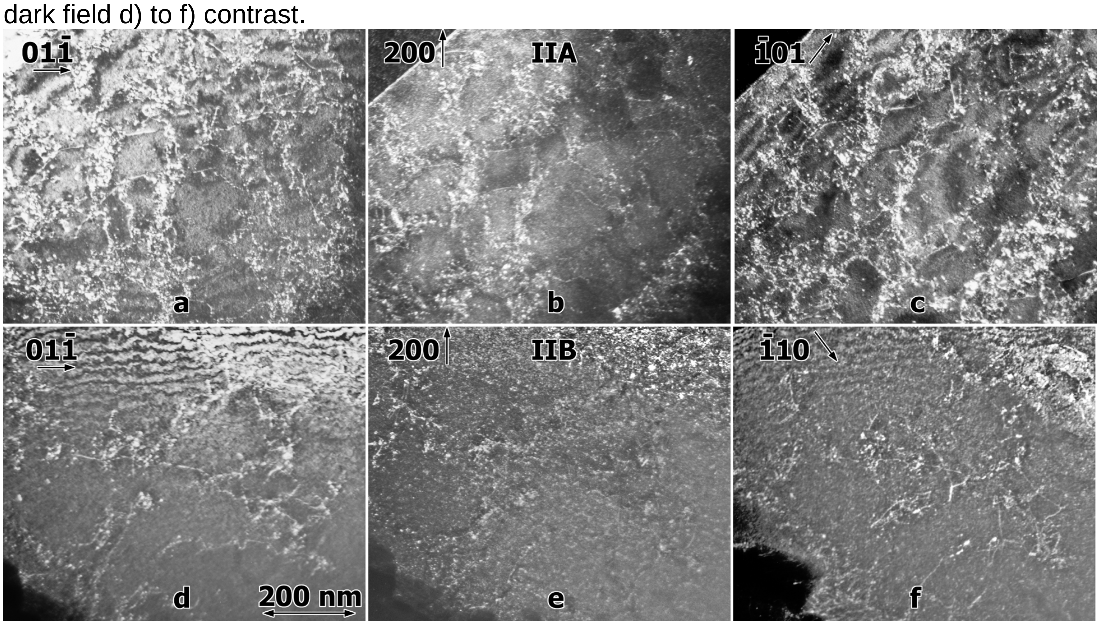

Figure 6. Microstructures in specimens IIA and IIB shown in dark field contrast.

$$\tfrac{a}{2}[\bar{1}11] + a[100] = \tfrac{a}{2}[111]$$

and leave a different loop and the original $\tfrac{a}{2}[\bar{1}11]$ dislocation unaltered. However, removal of the $\tfrac{a}{2}[111]$ loop is more difficult, requiring interaction only with other $\tfrac{a}{2}[111]$ dislocations. However, once dislocations break free of the subgrain boundaries, they appear to move individually; channeling is not required.

A recent paper concludes that hardening cannot be simply accounted for by the formation of small loops decorating dislocations present prior to irradiation.[5] Precipitation is likely to play a role. In that work, images in $\bar{g}$=200 contrast revealed very fine structure, interpreted as very fine precipitation. The present results do not reveal this fine uniform precipitation. A possible explanation lies in irradiation temperature differences, the present results for specimens at 327ºC and the earlier results at 250ºC (to a high dose at 302ºC). The hardening phase in F82H is probably more stable at lower temperatures. However, given the expected increase in strength following irradiation to 5 dpa at 330ºC, post-irradiation deformation studies on specimens expected to be available shortly at 5 dpa should be of great interest.

Conclusions

Miniature sheet specimens of F82H have been examined following irradiation to 2.7 dpa at 327ºC in order to study post-irradiation deformation behavior. It is found that

1) Deformation in irradiated specimens is highly localized so that TEM specimens prepared more than 1 mm from the fracture surface usually showed no effects of deformation.
2) Surface slip steps created during postirradiation deformation are poorly defined similar to unirradiated Fe-9Cr specimens, indicating that channel deformation did not control.
3) Effects of irradiation are identified. Fine structure, probably consisting of small dislocation loops, formed around dislocations in martensite lath boundaries.
4) Hardening is attributed to interaction of sub-grain boundary dislocations with the irradiation induced loops. However, the hardening is insufficient to cause channel deformation.

FUTURE WORK

This work will be continued when specimens irradiated to 5 dpa are available.

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