1.5 TENSILE FRACTURE MECHANISM OF HFIR-HEAVILY-IRRADIATED F82Hs — H. Sakasegawa, H. Tanigawa, T. Hirose, M. Ando (Japan Atomic Energy Agency), Y. Katoh, C. O. Stevens, and M. R. McAlister (Oak Ridge National Laboratory)

OJECTIVE

The objective of this work is to study the tensile fracture mechanism of F82Hs heavily irradiated up to about 87 dpa at high temperatures in HFIR (JP 28&29) using three dimensional fractography [1]. This work is part of the U.S. Department of Energy – Japan Atomic Energy Agency fusion materials collaboration.

SUMMARY

Irradiation embrittlement and hardening of tensile properties were observed in the heavily irradiated F82Hs at high temperatures, though it is still necessary to confirm the result of diametric analysis of silicon carbide passive temperature monitors. For F82Hs irradiated at 573 K, the three dimensional fractography revealed that the fracture mechanism was affected by irradiation. Dimples became smaller and shallower after irradiation, and grain boundary sliding was observed. These results contribute to development of a tensile fracture mechanism model explaining how the fracture is affected by irradiation.

PROGRESS AND STATUS

Introduction

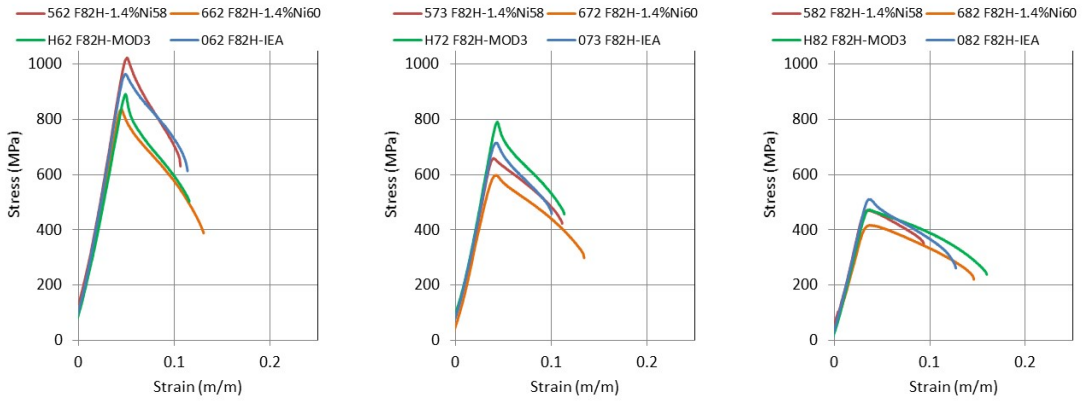
The current design technology is based on the guarantee that it is safe to ignore effects of defects which cannot be detected through normal non-destructive inspecting techniques, and to assume the fracture mode is plastic collapse. Namely, it presupposes that the structural material has adequate ductility [2]. However, it is well known that the ductility of reduced activation ferritic/martensitic steels drastically degrades and uniform elongation becomes near zero accompanying significant irradiation hardening after irradiation around 573 K to less than a few dpa. Therefore, it is important to study the tensile fracture mechanism after irradiation. The result should be considered in the design technology of test blanket modules for the actual usage of F82H as a blanket material with appropriate structural soundness.

Experimental Procedure

The materials evaluated are F82H-IEA (Fe-8Cr-2W-0.2V-0.04Ta-0.1C), F82H-MOD3 (Fe-8Cr-2W-0.2V-0.09Ta-0.1C), and F82H-1.4 % Ni (Fe-8Cr-2W-0.3V-0.02Ta-0.07C-1.4Ni^{58} or Ni^{60}). These were irradiated up to around 87 dpa at 573, 673, and 773 K (JP 28&29). After disassembling the capsules, high temperature tensile tests were performed in the cell 2 in the Building 3025E of Oak Ridge National Laboratory using the SS-J3 type tensile specimen (thickness: 0.75 mm, width: 1.25 mm, and gage length: 5 mm) at their irradiated temperatures in vacuum under a cross head control of 0.002 s^{-1}. After tensile test, three dimensional fractography was performed using the JEOL JSM-6010LA in the cell 4, and the software Alicona imaging Mex5.1 [1].

Results

Figure 1 shows the result of high temperature tensile tests at irradiated temperatures of 573, 673, and 773 K [3]. In all the results, irradiation hardening and embrittlement were observed. F82H-MOD3 showed tensile properties comparable to that of F82H-IEA, though it had higher tantalum content. F82H-1.4%Ni^{58} which produced 900 appm of helium demonstrated the minimum ductility, but F82H-1.4%Ni^{60} still showed ductility larger than 10 %.



(a) 573 K **(b) 673K** **(c) 773K**

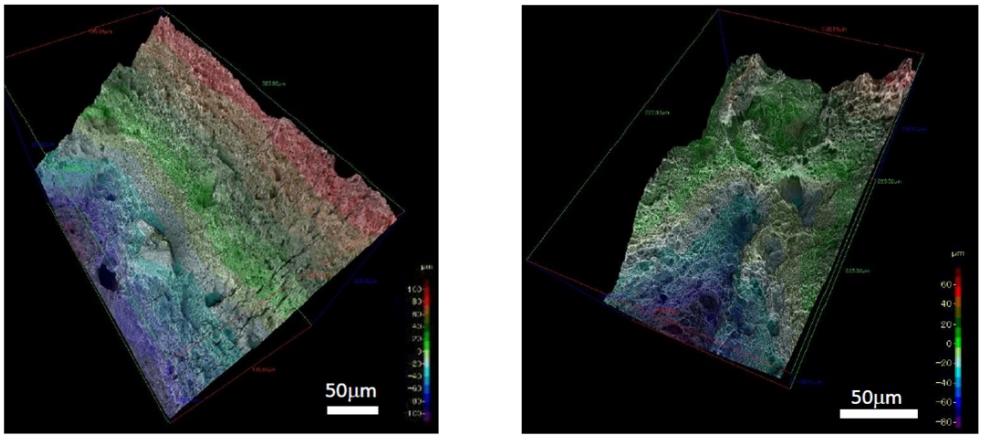
Figure 1. High temperature tensile test results of irradiated F82H alloys. [3]

Table 1 shows the result of diametric analysis of silicon carbide passive temperature monitors. For the irradiation at 573 K, no significant differences were observed between planned and analyzed temperatures. However, for the other irradiation temperatures, significant differences were observed. In future work, it is necessary to confirm this result performing hardness test and room temperature tensile test. In the present work, we focused on the specimens irradiated at 573 K only.

Figure 2 shows the result of three dimensional fractography of F82H-IEA and F82H-MOD3 before and after irradiation [2]. For the unirradiated F82H-IEA, a few large and deep equiaxed dimples were observed. On shear fracture surfaces, small elongated dimples were mainly observed. For the irradiated F82H-IEA, a few small and shallow equiaxed dimples were observed, and for the unirradiated F82H-MOD3, large and deep equiaxed dimples with inclusions were observed. Small elongated dimples were observed on shear fracture surfaces, as observed in F82H-IEA. For the irradiated F82H-MOD3, small and shallow equiaxed dimples were observed. In both F82H-IEA and F82H-MOD3, smaller and shallower dimples were observed after irradiation. These obtained results conform to the observed irradiation hardening and embrittlement, as shown in Figure 1.

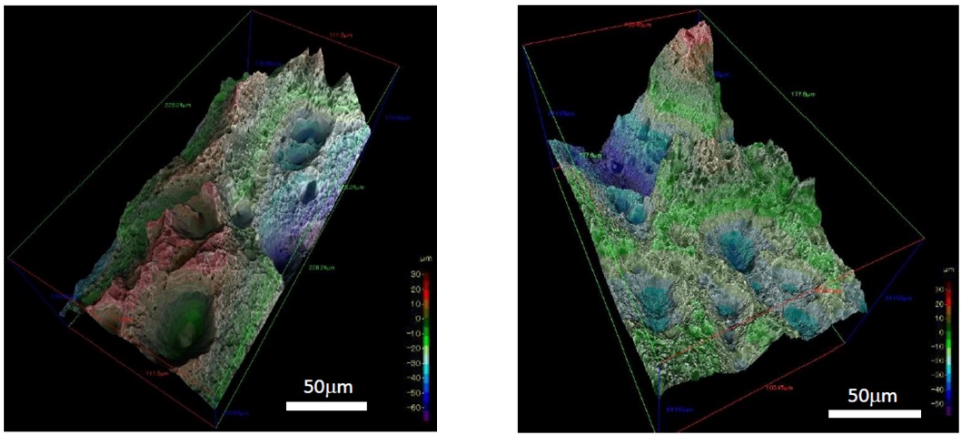
Table 1. Diametric analysis result of passive temperature monitors.

Planned temperature (K)	Specimen ID	Analyzed median temperature (K)
573	JP29TM0704	591.6
	JP29TM0708	557.3
673	JP28TM0702	593.5
	JP28TM0704	587.7
773	JP28TM0902	620.2
	JP28TM0904	612.3



Unirradiated **87 dpa**

(a) F82H-IEA

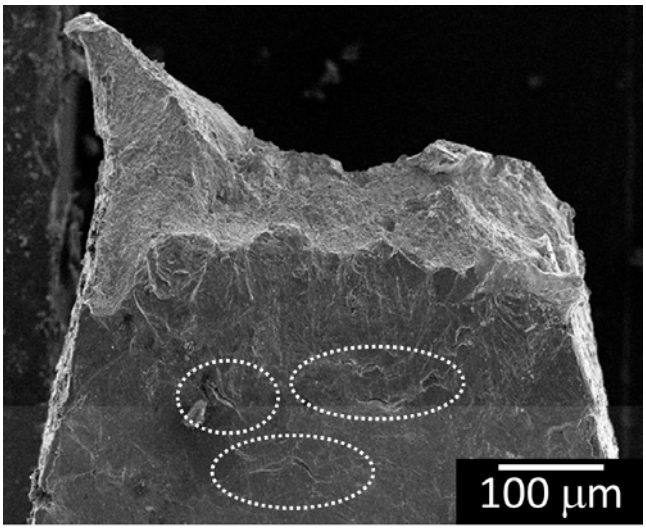


Unirradiated **87 dpa**

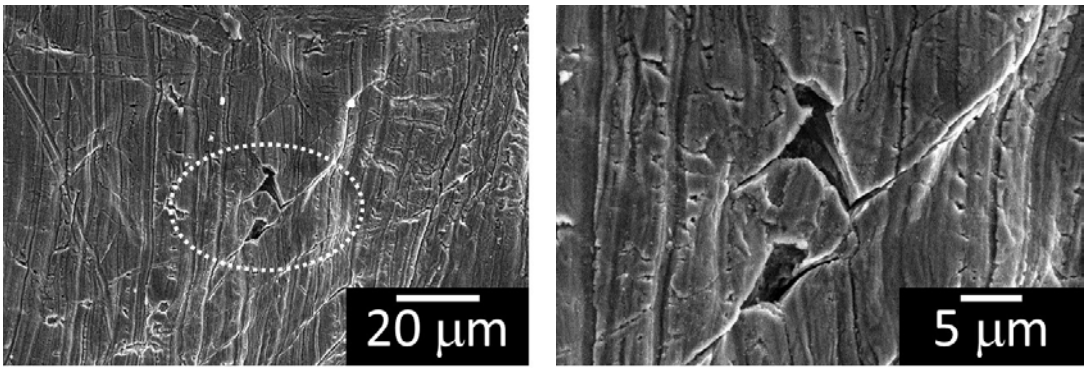
(b)F82H-MOD3

Figure 2. Fracture surface of F82H specimens tested at 573 K. [2]

Figure 3a shows the side of specimen of F82H-IEA after irradiation. Grain boundary sliding was observed. In Figure 3b, grain boundary sliding was more clearly observed in F82H-1.4 % 58Ni. These are representative results and grain boundary sliding was also observed in other irradiated F82Hs irradiated in JP 28&29. The irradiation hardening within the grain possibly caused relative strength degradation on grain boundaries. Grain boundary sliding can give a crack initiation site and enhance the degradation in ductility after irradiation. Though further observations are still necessary, grain boundary sliding possibly has an important role in tensile fracture mechanism.



(a) F82H-IEA



(b) F82H-1.4 % 58Ni

Figure 3. Grain boundary sliding in F82H samples tested at 573 K.

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References

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[2] H. Tanigawa et al., Impacts of inclusion on fracture process of reduced-activation ferritic/martensitic steels, ICFRM-17, Aachen, Germany, 11-16 October (2015).
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