Dynamic Mechanical Properties of Reduced Activation Ferritic Steels

T. Hirose [1)], H. Tanigawa [2)], M. Ando [2)], A. Kohyama [1)] and S. Jitsukawa [3)]

[1)] Institute of Advanced Energy, Kyoto University, Uji, Kyoto, Japan
[2)] Naka Fusion Establishment, Japan Atomic Energy Research Institute, Ibaraki, Japan
[3)] Tokai Establishment, Japan Atomic Energy Research Institute, Ibaraki, Japan

e-mail contact : hirose@iae.kyoto-u.ac.jp

Abstract: A fatigue test method by a miniaturized hourglass-shaped fatigue specimen has been developed for International Fusion Materials Irradiation Facility (IFMIF) and sufficient potential as the alternative to a conventional large specimen was presented. Furthermore, focused ion beam micro-sampling method was successfully applied to microstructural analysis on fracture process. Where, the effects of displacement damage and transmutation helium on the fatigue properties of Reduced Activation Ferritic/Martensitic Steels, RAFs, were investigated. Neutron irradiation and helium-ion-implantation at ambient temperature caused radiation hardening to degrade fatigue lifetime of F82H steel. Microstructural analysis revealed that local brittle fractures occurred at early stage of fatigue tests was the origin of the degradation.. No significant difference in fatigue life degradation was detected with and without implanted helium. This result suggests that 100 appm helium implanted has no impact on fracture life time under neutron irradiation.

1. Introduction

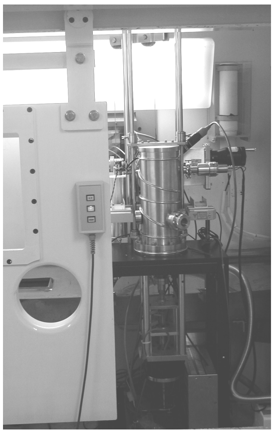
As the important part of the fusion reactor structural materials R & D activities, establishment of mechanical property database has been extensively carried out[1]. Although IEA low activation materials working group has been working together more than a decade, the database for IEA reference materials, such as F82H and JLF-1, is still insufficient, where dynamic property data are quite poor and evaluation methods have not been well established.

Looking back to the reduced activation ferritic/martensitic steel (RAFs) R & D activities, due to the extensive R & D activities in these two decades, the leading candidate ferritic steels are now ready to establish industrial material database for designing breeding blanket component[2]. However, the dynamic mechanical property database is quite limited and furthermore data-set of radiation effects is very much limited. In fusion applications, the structural materials will be exposed to cyclic stress caused by temperature cycling from reactor operation. Therefore, fatigue properties may have strong impact on economical competitiveness of fusion energy.

2. Establishment of Testing Method for Dynamic Mechanical Properties

This work starts from the establishment of fatigue properties evaluation methods by small specimen test technology (SSTT) to be applied for neutron irradiated ferritic steel samples.

Testing machine has been designed and installed in the hot-laboratory of Oarai branch, Institute for Materials Research, Tohoku University. The apparatus of the fatigue test machine is shown in Figure 1. Remote handling is considered to be difficult for fatigue tests, such as a gripping of specimens and an attachment of extensometers. In this work, since the remote handling issues were regarded as the most important, a chucking device was also developed for easy test preparation. A laser extensometer, which enables monitoring deformation during the test without any specimen contact, was applied for monitoring dynamic deformation.



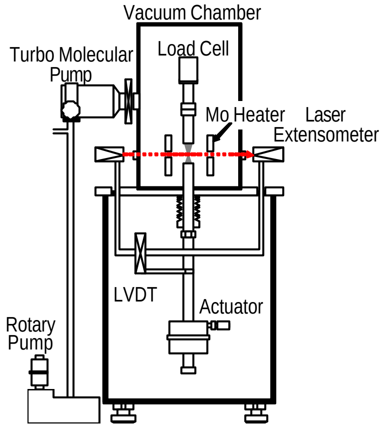


Figure 1 Apparatus of the fatigue test machine installed to hot cell and its schematic illustration.

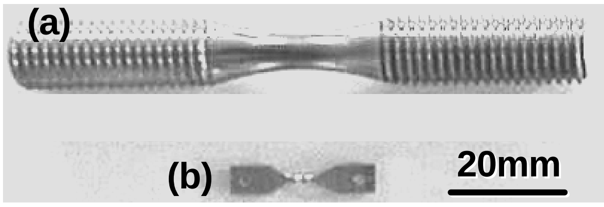


Figure 2 Specimen used in this work, (a): Conventional hourglass specimen, (b): SF-1 specimen.

It is well known that the hourglass type specimen demonstrates excellent buckling-resistance, which is a very important issue in miniaturizing specimens for push-pull tests. In this work miniaturized hourglass specimen SF-1 (Figure 2) were used. This specimen was originally designed for International Fusion Materials Irradiation Facility (IFMIF) but has never been confirmed its applicability. The fatigue lifetimes of JLF-1 steel[3], 9Cr-2W-Ta,V RAFs, IEA heat, are shown in Figure 3, compared with those from conventional large specimens. These results indicate that the miniaturized specimen test method can be applied to evaluate the fatigue lifetime as the alternative to the conventional one[4].

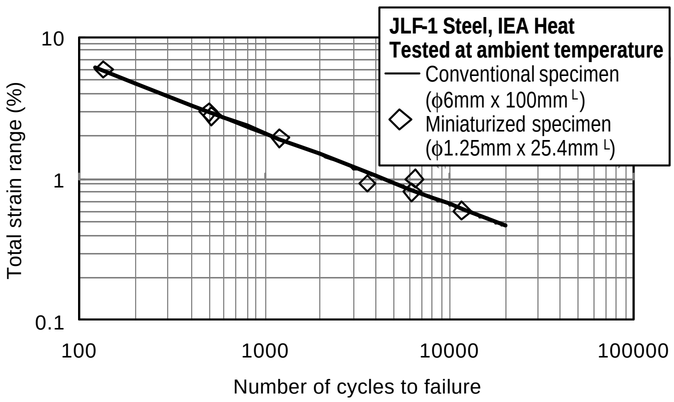


Figure 3 Specimen size effects on fatigue lifetime of RAFs JLF-1 IEA Heat.

3. Radiation Effects on Dynamic Mechanical Properties of RAFs

Neutron damage effect and helium implantation effect to evaluate displacement damage and transmutation damage on fatigue lifetime are shown in

Figure 4. Although the damage fluence was very low, the irradiated materials showed almost 100 MPa of irradiation hardening, which was enough to examine radiation embrittlement and fatigue properties under irradiation. Generally, neutron and helium ion irradiated F82H showed shorter lifetime than that of unirradiated ones.

As shown in this figure, the neutron irradiated samples showed the shortest lifetime. And the reduction of the N_f was significant for the large strain test condition. The analyses of fracture surface revealed that the significant reduction of N_f in large strain test was caused by local brittle fracture[5]. On the other hands, the brittle fracture surface was not observed at helium-ion implanted samples. There are some reports that transmutation helium degrades the ductility of RAFs[6]. Although, helium-ion implantation did not reduce fatigue lifetime in this work, which may suggest that transmutation helium has no significant effects on fatigue properties, further efforts are essential to be conclusive[7].

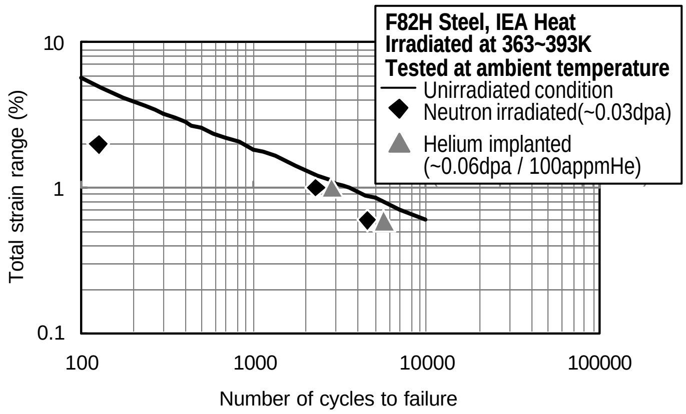


Figure 4 Radiation effects on fatigue lifetime of RAFs, F82H IEA Heat.

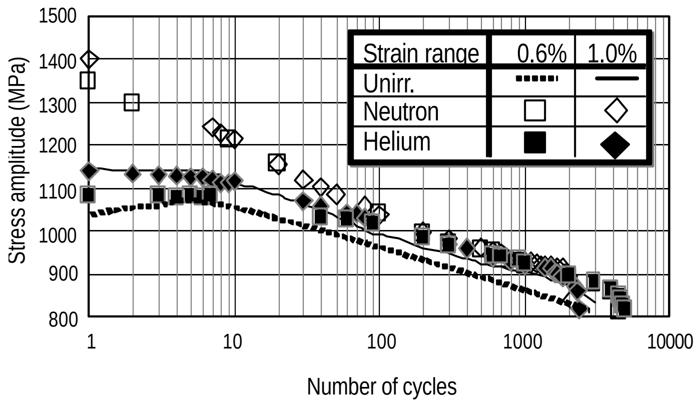


Figure 5 Radiation effects on stress amplitude of RAFs, F82H IEA Heat

The neutron and helium irradiation effects on the stress amplitudes are presented in Figure 5. Total stress amplitude is plotted as a function of the number of cycles. The increase of stress amplitude related to the radiation hardening was observed in the neutron irradiated samples. F82H demonstrated cyclic softening before and after the irradiation.

4. Microstructural Analysis of Fatigue Fractured Samples

To establish clear insights about the radiation fatigue and radiation creep-fatigue, a new method to analyze microstructural evolution has been developed and applied. Microstructural evolution after fatigue tests was also investigated with Focused Ion Beam (FIB) micro-sampling system and Transmission Electron Microscopy (TEM) [8].

The procedure for making TEM thin foils out of the deformed region near a crack tip on fatigue-fractured specimen is shown in Figure 6. The process utilizes FIB micro-sampling system (FB-2000A, Hitachi). The system is capable at picking up tiny

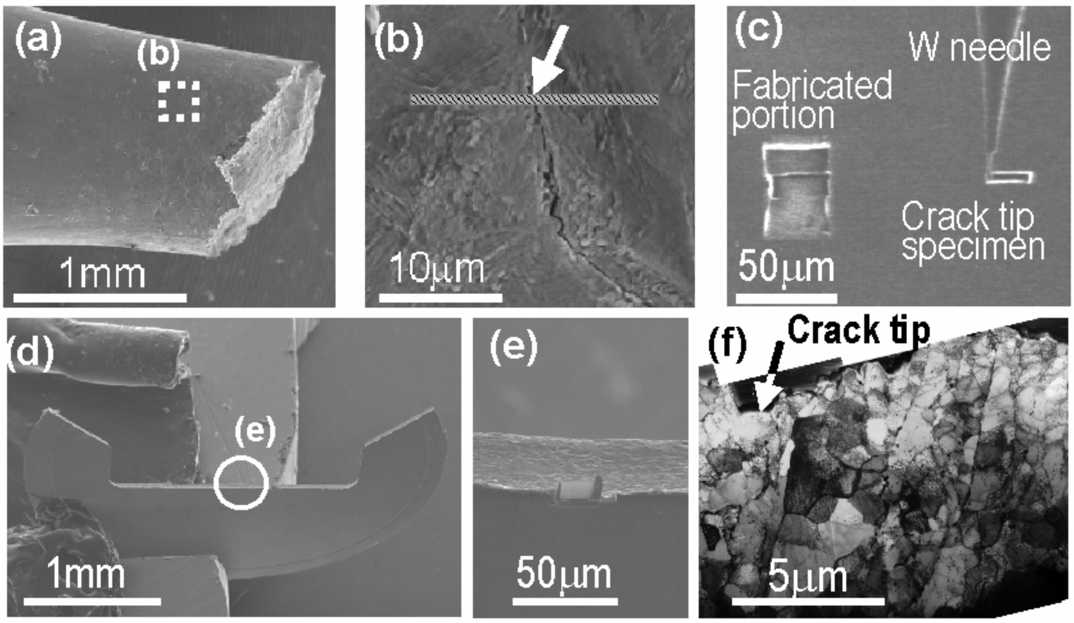


Figure 6 Fabrication process of TEM foil specimen with FIB micro sampling system. (a) Fatigue-fractured specimen.(b) Cover the area with W deposition (c) Remove periphery of the area, weld needle to the remained area, then cut off and pick up the sample (d) Weld the sample onto TEM mesh and cut off the W needle (e) Thin the sample to TEM foil (f)Typical fatigue-fractured microstructure of F82H IEA heat.

(a) Unirradiated (strain range=1.5%, N_f = 1.5x10^3) (b) Neutron irradiated (strain range=1.0%, N_f=2.3x10^3)

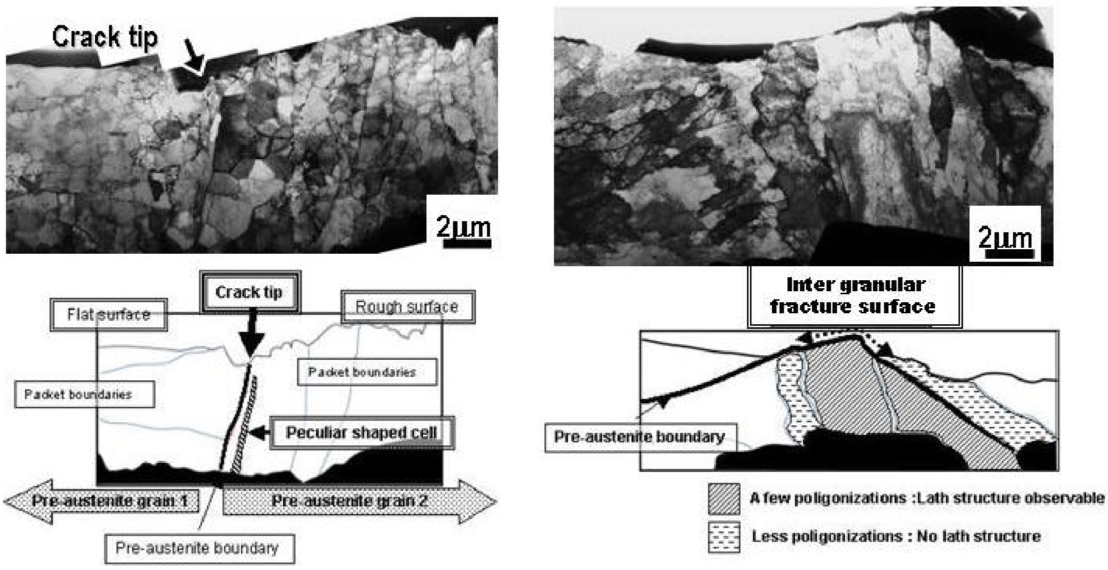


Figure 7 Radiation effects on fatigue fracture apparatus of RAFs, F82H IEA Heat.

rectangular samples from bulk specimen. The dimensions of the smaller samples are 20 μm x 20 μm x 50 nm. Figure 7-(a) shows typical TEM micrograph on fatigue crack tip of unirradiated specimen. The TEM sample was fabricated from crack tip. As shown in this figure, typical lath structure of RAFs was destroyed during dynamic deformation. A crack was initiated along with the grain boundaries. The dynamic deformed microstructures, reduction of dislocation densities and local gathering of dislocations were observed all over the sample. However, as-received F82H has martensite lath structures that contain a number of dislocations. Therefore the cell structure formation in F82H caused to reduce the number density of dislocation and soften the steel. In the previous work, micro indentation tests revealed that hardness of cell structure was smaller than that of lath structure.

As for the irradiated specimen (Figure 7-(b)), deformed microstructures were observed even after irradiation. The peculiar shaped cells are extended with the crack initiation site as the starting point. The cracks propagated along with the boundary of sub grain with peculiar shape. According to these evidences, there was no significant difference in fatigue-fractured process before and after neutron irradiation. It is considered that neutron irradiation did not alter the microstructural evolution during fatigue tests in this case.

5. Summary

Dynamic mechanical properties evaluating techniques has been developed with small specimen test technology. The specimen used in the techniques is much smaller than conventional specimen for irradiation environment. The specimen volume has significant benefits to irradiation in the limited target cell at IFMIF.

High dose neutron irradiation effects to confirm DEMO reactor level damage will be investigated as a part of on-going JAERI-DOE collaboration program. This is the way to go for the validation of the material property prediction model for ITER and DEMO reactor to be obtained by IFMIF.

References

[1] A. Kimura, et al., "Recent Progress in Reduced Activation Ferritic Steels R&D in Japan", FT/1-1Ra, in these Proceedings.

[2] M. Enoeda, et al., "Design and Technology Development of Solid Breeder Blanket Cooled by Supercritical Water in Japan", FT/1-8, in these Proceedings.

[3] A. Kohyama, Y. Kohno, M. Kuroda, A. Kimura and F. Wan, J. Nucl. Mater., 258-263 (1998), 1319-1323.

[4] T. Hirose, H. Sakasegawa, A. Kohyama, Y. Katoh and H. Tanigawa, J. Nucl. Mater., 283-287, (2000) 1018-1022.

[5] T. Hirose, H. Tanigawa, M. Ando, T. Suzuki, A. Kohyama, Y. Katoh and M. Narui, ASTM STP 1418 (2002) in printing.

[6] A. Kimura, T. Morimura, R. Kasada, H. Matsui, A. Hasegawa and K. Abe, ASTM STP 1366 (2000) 626-641.

[7] T. Hirose, H. Tanigawa, M. Ando, A. Kohyama, Y. Katoh and M. Narui, presented in ICFRM-10 (2001) to be published in J. Nucl. Mater.

[8] T. Hirose, H. Tanigawa, M. Ando, A. Kohyama, Y. Katoh and S. Jitsukawa, Mater. Trans., Vol. 42, No. 3 (2001) 389-392.