Study of Strength Factor in Multi-scale Model for Neutron-irradiated Materials by means of Nano-micro Specimen Technology

Improved radiation resistance was found in 9Cr-2W steel with 0.1% Si after neutron irradiation. The microstructure, mechanical properties and positron annihilation behavior were studied systematically. Lower number of loops and higher number of nano-precipitates were formed in with Si. It suggests the resistance could be caused by more sinks and defect interaction.

9Cr-2W low activation ferritic steel is one of candidate for the first wall structure materials in fusion reactor system. This series of steels have been developed in Kyoto U, and surveyed several points, especially on effect of Si addition and low temperature embrittlement [1]. AFM-A(w/Si) and AFM-B(w/o Si) were neutron-irradiated in JMTR to $5x10^{23}$ n/m^2 at 290℃ (1,178 hr, 99M-14U, #2342). The cooling time was 15 years. Under ICC program, Post Irradiation Experiment (FIB, AC-TEM, Tensile test, Nano-hardness test) was carried out at IMR Oarai Center, except positron CBD measurement at Kyoto U.

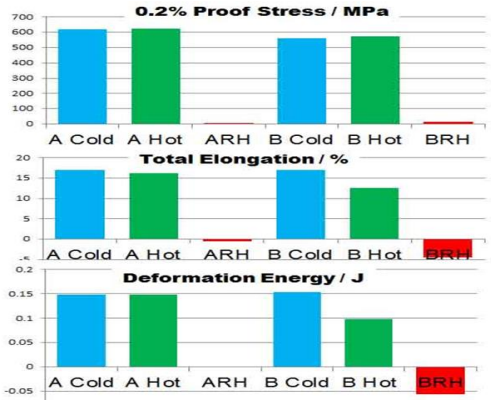

Fig. 1. Yield stress, elongation and deformation energy before and after irradiation. B showed intensive radiation embrittlement.

Fig. 1 shows yield stress, elongation and deformation energy before and after the irradiation, where red bars show induced hardening, elongation loss and reduction of the energy. Comparing with AFM-A (w/ Si) and AFM-B (w/o Si), Si addition improved in radiation-hardening very clearly, because of small hardening and elongation loss.

As shown in fig 2, many black dots were observed in both materials by TEM. By precise observation those black dots were confirmed as radiation induced dislocation loops with 5 nm level. In the comparison, higher density of loops were founded in AFM-B. The result indicates the addition of Si improve the irradiation resistance due to

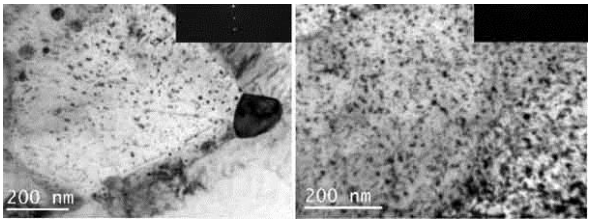

Fig. 2. Black dots formed in AFM-A (w/ Si) and AFM-B (w/o Si).

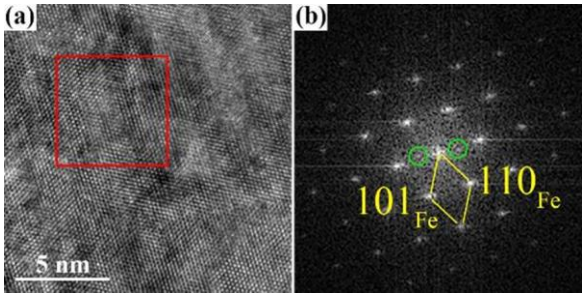

Fig. 3. HRTEM image of with Si sample and FFT image of red box. It suggests nano-precipitate of G phase.

enhancement of internal sinks and defect trapping.

Fig. 3 shows HRTEM and IFFT images from AFM-A (w/o Si). The distances of $(110)_{Fe}$ and $(210)_{Fe}$ calculated via FFT image. The spots with green circle are not belonging to the reciprocal lattice of alpha-Fe. Moreover, PA CDB showing a phase separation occurred. We assume these are G phase with 2-3 nm, at this moment [2]. Thus, keeping an appropriate amount of Si is helpful to improve the resistance to neutron irradiation damage. Several papers will be published in near future.

References

[1] A. Kimura, et. al., J. Nucl. Mat., 283-287 (2000) 827.
[2] Y. Matsukawa, et. al. Acta Mat. 116 (2016) 104e113

Keywords: radiation damage, neutron irradiation, strength
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