§14. Lifetime Investigation of Reduced Activation Ferritic Steels for Steel-based Blanket in Fusion Reactors

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Reduced activation ferritic/martensitic (RAFM) steel is the primary near-term candidate for the blanket structural material of nuclear fusion reactors. Loading of the structural materials in a fusion reactor is, besides the plasma surface interactions, a combined effect of high heat fluxes and neutron irradiation. In fusion applications, the structural materials will be exposed to cyclic stress caused by temperature cycling from reactor operation. Therefore, investigation of fatigue is essential to reactor design. Although fatigue tests on RAFM steel started recently, few data on fatigue properties of RAFM have been obtained up to now. This study focused on the influence of a neutron irradiation to fatigue property for the purpose of constructing design criteria for fatigue property.

The material used was F82H IEA heat which was normalized at 1313 K for 40 min air-cooled and tempered at 1023 K for 60 min air-cooled. The mini-sized hourglass type specimens (SF-1) were used for low cycle fatigue (LCF) tests. It is well known that the hourglass type specimen has good resistance to buckling, which is a very important issue to miniaturize specimens for push-pull tests. The fatigue specimens were irradiated at 423 K and 573 K in Japan Materials Testing Reactor (JMTR), and nominal displacement damage was 0.02dpa. For LCF test using before/after irradiation SF-1 specimen, an electromotive testing machine with a 200 kg load cell was used. Diametral strain controlled fatigue tests were carried out with a triangular stress waveform and a total diametral strain range, $\Delta\varepsilon_d$ of 0.4-0.7 %. $\Delta\varepsilon_d$ was converted to total axial strain range, $\Delta\varepsilon_a$, by the following formula;

$$\Delta\varepsilon_a = (\sigma / E)(1 - \nu_e) - 2\Delta\varepsilon_d,$$

where σ is applied stress, E the elastic modulus, ν_e is the elastic Poisson's ratio.

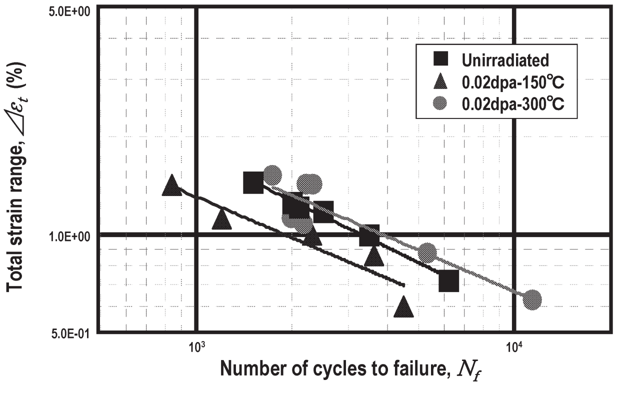

Fig. 1 The effects of neutron Irradiation on the Low cycle fatigue lifetime of F82H IEA-heat.

The neutron irradiation effects on the low cycle fatigue lifetime are presented in Fig. 1. The total strain range is plotted as a function of the number of cycles to failure, N_f. As shown in this figure, the neutron irradiated samples at 423 K showed the shortest lifetime. As for this, an irradiation defect introduced by neutron irradiation causes irradiation hardening, and it lead to high stress amplitude during repetition of fatigue cycle. And also, the plastic strain range decreased duration of fatigue cycle. Thus, cyclic softening was clearly indicated in this study. Especially, neutron irradiated samples were shown significant cyclic softening decreasing about 70 % of unirradiated samples. Meanwhile, neutron irradiated samples at 573 K were shown about the same fatigue lifetime with unirradiated samples. These results correspond to the results of Vickers hardness test well.

The reversal to failure, $2N_f$, is plotted against half of the elastic strain range, $\Delta\varepsilon_e/2$, and the plastic strain range, $\Delta\varepsilon_p/2$, as shown in Fig. 1. The figure indicates that, over the range of lives studied, the plastic strain was the dominant portion of the total strain range. The elastic strain was only for the material constant, which is the dominant portion of high cycle fatigue regime. From the data, it is apparent that the fatigue transition life, that is the point where the elastic and plastic strain ranges are equivalent, $\Delta\varepsilon_e/2 = \Delta\varepsilon_p/2$, occurs at fatigue lives of around 10^4 cycles to failure. The transition life is usually assumed to delineate the low cycle fatigue behavior where the plastic strain dominates and the high cycle fatigue life where the elastic response dominates.

The fatigue response can be well represented by the well known strain-life equation, Manson-Coffin's relation;

(1) 0.02dpa@423 K:
$$\Delta\varepsilon_t/2 = \Delta\varepsilon_e/2 + \Delta\varepsilon_p/2 = 0.339\,(N_f)^{0.037} + 160.488\,(N_f)^{-0.764}$$

(2) 0.02dpa@573 K:
$$\Delta\varepsilon_t/2 = \Delta\varepsilon_e/2 + \Delta\varepsilon_p/2 = 1.173\,(N_f)^{-0.112} + 262.130\,(N_f)^{0.755}$$

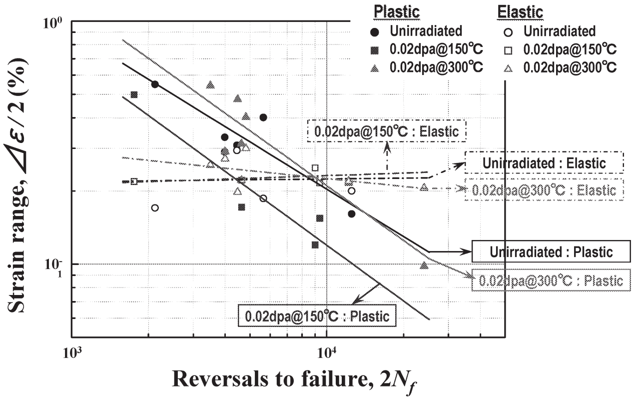

Fig. 2 Strain-life plot indicating the relative contributions of the elastic and plastic strain range to the failure life of F82H IEA-heat.

References

1) Hirose, T., et al. : J. Nucl. Mater. 307-311 (2002) 304.
2) Kim, S.W., et al. : J. Nucl. Mater. In press (2007)