§24. Fatigue Life Evaluation of Reduced Activation Ferritic Steel using Small Specimen

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1. Introduction

Reduced activation ferritic/martensitic (RAFM) steel has been developed as a candidate structural material for FFHR and DEMO. Since the fusion reactor structural material must support dynamic loads under neutron irradiation, the fatigue behavior of the RAFM steel under/after neutron irradiation must be clarified for designing the fusion reactor blanket.

Development of the fatigue life evaluation method using small specimen is necessary for evaluating the neutron irradiation effect on it. Though the small fatigue specimen with several shapes such as round-bar, hourglass and flat-plate has been used in previous studies, verification was not enough whether these small specimens showed the same fatigue life as the standard specimen, which was the round-bar specimen with a minimum diameter of a few millimeters. Authors have reported the difference of the fatigue life between the standard specimen and the small hourglass specimen, which has been the standard small fatigue specimen in Japan to evaluate the fatigue life of RAFM steels [1]. On the other hand, the small round-bar specimen showed almost no difference of the fatigue life from the standard specimen [1].

The objective of this study is to develop the database of the fatigue life and its regression formula of the small round-bar specimen fabricated by the RAFM steel in order to establish the fatigue life evaluation method using small specimen.

2. Experimental

The reduced activation ferritic/martensitic steels, F82H-IEA and JLF-1 were employed for the fatigue test. The diameter of minimum cross-section and the gauge length of the small round-bar specimen were 0.85 and 3.4 mm (RB-0.85), 1 and 3.4 mm (RB-1) and 1.7 and 3.4 mm (RB-1.7), respectively. The gauge region of the specimen was polished using alumina slurry, whose conditions were optimized in this collaboration research last year.

Low cycle fatigue tests were carried out at room temperature in air under axial strain control using an electromotive testing machine with a 1 kN load cell fabricated by Kobe Material Testing Laboratory, Japan. A completely reversed push-pull condition was applied, and the total strain range was controlled using a triangular wave ($R = -1$) with an axial strain rate of about 0.1%/s. The axial strain was measured using an extensometer attached directly to the specimen. The total strain range ($\Delta\varepsilon_t$) was 0.4–1.5%. The fatigue life (N_f) was defined as the number of cycles at which the tensile peak stress dropped to 75% from the extrapolated line of the cyclic softening trend.

3. Results

Fig. 1 shows the relationship between total strain range ($\Delta\varepsilon_t$) and fatigue life (N_f) of the RB-0.85, RB-1, and RB-1.7 specimens of F82H-IEA, of the RB-1 specimen of JLF-1, and the regression curves of the standard specimen for comparison. It was clearly observed that the fatigue life of small round-bar specimen was very similar to that of the standard specimen and was ranged within a factor of 2 of the regression curve given by the following equations.

$$\Delta\varepsilon_t = 105N_f^{-0.66} + 0.80N_f^{-0.07} \text{ (F82H-IEA)}, \quad (1)$$

$$\Delta\varepsilon_t = 91.0N_f^{-0.60} + 1.02N_f^{-0.09} \text{ (JLF-1)}. \quad (2)$$

Generally, a very small number of grains across the specimen diameter could cause the mechanical properties (*e.g.*, strength, elongation, and fatigue life) of the small specimen to be different from those of the standard specimen. In this study, it was clarified that the number of grains across the specimen diameter did not affect the fatigue life of the round-bar specimen, which ranged from 9 to 100. Thus, the effect of specimen size on the fatigue life of RAFM steels was negligible under the test conditions in this study.

On the basis of this study, the same fatigue life as the standard specimen would be evaluated by using the small round-bar specimen, that were polished under the conditions optimized in this study. Therefore, the small round-bar specimen is an acceptable candidate for evaluating the fatigue life of the RAFM steels using small specimen. However, the small round-bar specimen exhibits lower resistance to buckling than the small hourglass specimen under a relatively high strain range, which is an issue that remains to be resolved. It is important to optimize the size of the round-bar specimen for every test condition because the probability of buckling strongly depends on the specimen size (i.e., the diameter of the test section and the gauge length) and test conditions, especially when compressive strain is applied to the round-bar specimen.

1) S. Nogami, T. Itoh, H. Sakasegawa, H. Tanigawa, E. Wakai, A. Nishimura, A. Hasegawa, J. Nucl. Sci. Tech., 48-1 (2011) 60-64.

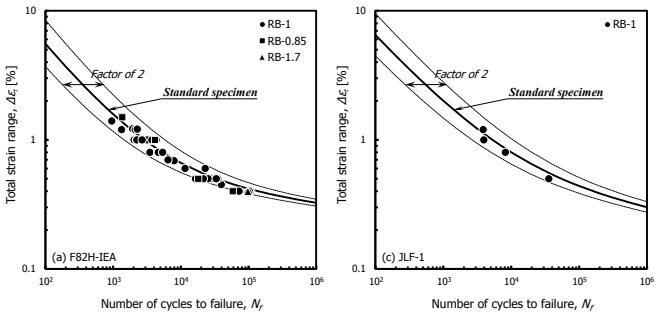

Fig. 1. Relationship between total strain range ($\Delta\varepsilon_t$) and fatigue life (N_f) of the RB-0.85, RB-1, and RB-1.7 specimens of F82H-IEA, of the RB-1 specimen of JLF-1, and the regression curves of the standard specimen.