§18. Development of Reduced Activation Ferritic Steels with Improved Heat Resistance and Elemental Property Characterization for High Cycle Efficiency Steel-based Blankets

Kohyama, A., Kim, S.W., Ogiwara, H. (Institute of Advanced Energy, Kyoto University)
Muroga, T.

It is critical for the blanket structural material of fusion reactor to understand fatigue behavior in order to estimate the safety margin, life-time and reliability in terms of the crack initiation and critical crack length before and after irradiation[1,2]. The existing database of the reduced activation ferritic steels (RAFs) (JLF-1 steels and F82H steels) including neutron irradiation effect are relatively rich compared with the other candidate materials. However experimental data such as fatigue life, fracture toughness and fatigue crack growth (FCG) are still insufficient for the blanket design. Fatigue testing of RAFs after neutron irradiation is supposed to be carried out in hot cells with remote control system. Considering limited ability of specimen manipulation in the cells, the specimen and the test method must be arranged for simple operation. The objective of this study is to examine and understand the microstructural mechanism on the FCG behavior of JLF-1 steels. The effects of test specimen size were discussed within the Paris region. Especially, the correlations between crack growth behavior and microstructure were focused on.

The materials used were reduced activation ferritic/ martensitic steels, JLF-1 IEA heat (Fe-9Cr-2W,V,Ta). Heat treatments were normalized at 1323 K for 1 h followed by air cooling (AC), followed by tempering at 1053 K for 1 h followed by AC, and post-welding heat treatment (PWHT) at 740°C for 3h furnace-cooled (FC) was applied. FCG tests were carried out according to ASTM E647 standard using a full-sized compact tension (CT) specimen and half-size CT specimen at room temperature. The crack growth test results were summarized in terms of FCG rate (da/dN) versus stress intensity factor range (ΔK) curves using an incremental polynomial method. These curves are divided into regions I, II and III. The FCG rate in the sub-critical region II is related to the stress intensity factor range as follows 3);

$$da/dN = C(\Delta K)^m, \qquad (1)$$

where m is the Paris exponent and C is the Paris constants. Fracture surfaces of tested specimen were observed using a scanning electron microscope (SEM) in order to determine the fracture mode.

The variation of FCG rate (da/dN) with stress intensity factor range (ΔK) for full-size and half-size CT specimen at room temperature is shown in Fig. 1. Stable fatigue crack growth (Paris region) started from approximately 17 MPa-m$^{1/2}$ of ΔK, although the initial stage of the fatigue crack growth showed unstable crack growth. The FCG rate of half-size specimen was almost the same as those of full size specimens as shown in Fig. 1. Therefore, it is considered that the specimen size slightly affected the FCG rate for JLF-1 steels at RT. Although it is still necessary to evaluate of crack closure and fracture mechanics, it is suggested that the FCG behavior of JLF-1 steels can be evaluated by using small sized specimens at RT.

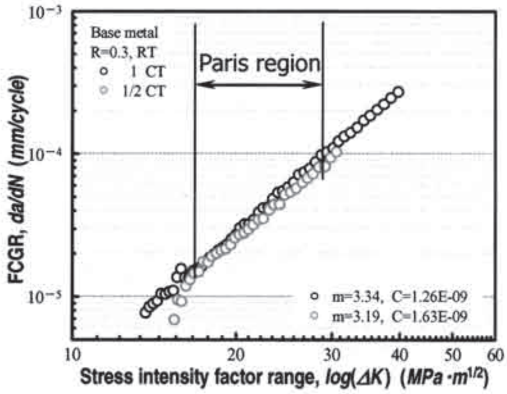

Fig. 1. Fatigue crack growth rate as a function of stress intensity factor range in full-size and half-size CT specimen at room temperature

Fig. 2 shows the SEM images of the fracture surface of Paris region in the FCG tested specimen. In this figure, trans-granular fracture surface accompanied by the striation pattern, which is a particular striped pattern of model I fracture, and the local ductility tearing were observed. The clear difference between each fracture surface accompanying the increase (Fig.2 A→B→C) in ΔK was not confirmed.

Paris region (ΔK=17~29 MPa-m$^{1/2}$)

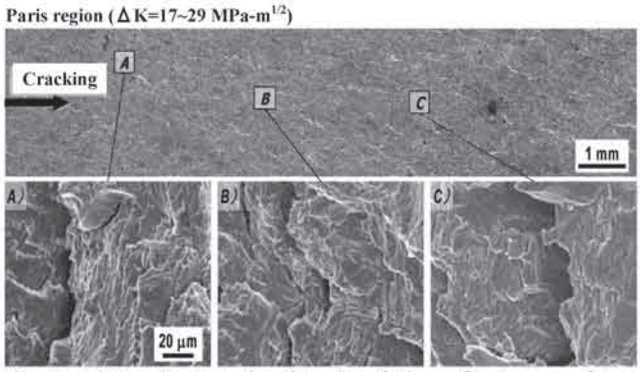

Fig. 2. SEM micrographs showing fatigue fracture surfaces after FCG test at room temperature

These results showed the possibility of evaluation using miniaturized CT specimen in evaluation of the FCG in JLF-1 steels.

References
1) Kohno, Y. et al. : J. Nucl. Mater. 271-272 (1999) 145.
2) Nishimura A et al. : J. Nucl. Mater. 258-263 (1998) 1242.
3) Paris, P.C. et al. : Trend. Engng. 13 (1961) 9.