# §16. Evaluation of Fracture Toughness and Tensile Properties of Reduced Activation Materials with Miniaturized Specimen

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Evaluation of fracture toughness requires the use of full sized compact tension (CT) or 3-point bending (3PB) specimens that are 25.4mm thick. However, the first wall and blanket of a fusion reactor are thin wall structures, several millimeters thick. Furthermore, the irradiation volumes available in IFMIF are very limited. Therefore it is mandatory to establish small specimen test techniques for fracture toughness testing of the fusion reactor materials.

Specimen miniaturization for fracture toughness testing has been mainly concentrated on CT specimens because the load-line displacement can be precisely measured with a clip gage for CT specimens, but not for 3PB specimens. However, 3PB specimens have many advantages over the CT specimens. Therefore, the authors have made efforts to develop test techniques for reliable evaluation of the fracture toughness of a reduced activation ferritic steel, JLF-1 using miniaturized 3PB specimens with thickness of 7.0, 5.0 and 3.3mm [1]. In this study, the test temperature dependence of the fracture toughness of JLF-1 is evaluated with miniaturized 3PB specimens. The temperature dependence of tensile properties of JLF-1 is also evaluated with miniaturized tensile specimens.

3PB specimens of 3.3mm thick, 5.0mm wide and 25mm long and tensile specimens with the gauge section of 1.2mm wide, 0.5mm thick and 5mm long were machined from a JLF-1 plate, having the composition, in wt%, 0.098C, 0.05Si, 0.5Mn, 0.002P, 0.004S, 8.92Cr, 2.00W, 0.20V, 0.098Ta, 0.0149N, 0.0001B, and balance iron. A fatigue testing machine (Shimadzu Servopulser of 50-kN capacity equipped with a 5-kN shear-type load cell) was used to introduce a well-defined crack and perform fracture toughness tests. For pre-cracking, the stress intensify factor, $\Delta K$, was controlled from the initial values of 14~16 $MPam^{1/2}$ to the final values of approximately 4~7 $MPam^{1/2}$ depending on test temperature and notch preparation. Because the fatigue pre-cracking should meet the requirements that for the final 3% of fatigue precrack extension $K_{fmax}(3\%) < 0.6(\sigma_{YS1}/\sigma_{YS2})K_Q$ and for the final 50% of fatigue precrack extension the maximum fatigue load, $P_{max}$, is no larger than $P_f = 0.5Bb_0^2\sigma_Y/S$ ($b_0$= W-$a_0$). Here, $\sigma_{YS1}$ and $\sigma_{YS2}$ are 0.2% offset static yield stresses at temperatures where fatigue precracking and fracture toughness testing were conducted, respectively. $\sigma_Y$ is the effective yield strength, defined as $\sigma_Y=(\sigma_{YS}+\sigma_{TS})/2$, where $\sigma_{TS}$ is the ultimate tensile strength. Fatigue cycling was conducted at room temperature with a sinusoidal waveform of 20Hz and the ratio of the maximum to minimum fatigue loads of 0.095.

The crack length, $a_0$, was controlled to be approximately 0.55W and the side grooves to be 0.25B (W and B are the width and thickness, respectively). A clip gage with the stroke of ±2mm was seated on a machined knife edge with 1mm deep and 2mm wide. Elastic-plastic fracture toughness tests by the single specimen method and plane strain fracture toughness tests were conducted in general accordance with the ASTM standards at temperatures from 294 to 77K at a cross-head speed of 0.01mm $s^{-1}$. The elastic-plastic fracture toughness tested specimens were heat-tinted and then fractured at 77K to measure the initial and final crack lengths. Tensile tests were also conducted at temperatures from 294 to 77K at an initial strain rate of $1\times10^{-3}$ $s^{-1}$.

In the temperature range between 294 and 206K where slow, stable crack extension was observed, the *J*-integral was measured according to the ASTM standards [2]. On the other hand, around 180K unstable cracking occurred during several loading-unloading cycles after yielding, and the area under the load-displacement record up to the unstable cracking was used to evaluate the fracture toughness. These $J_Q$ values were converted into $K_J$ by $K_J = (J_Q \times E)^{1/2}$, where E is the Young's modulus of JLF-1. It was found that the values of $K_J$ = 310~320 $MPam^{1/2}$ at room temperature are almost maintained up to around 220K and rapidly decreases below 208K, e.g., to one half of the RT values at 180K and to approximately only 20 $MPam^{1/2}$ at 77K. This value of 20 $MPam^{1/2}$ satisfies the criterion of B, W-$a_0$ > $2.5(K_{IC}/\sigma_{YS})^2$ and the shape of the fatigue pre-crack front was flat, indicating that it is the plane strain fracture toughness, $K_{IC}$.

Plots of yield and tensile stresses and uniform and total elongations against test temperature showed that around 190K both the strength and elongation change significantly. Below 190K, the yield strength increases rapidly and the work hardening capability decreases, whereas the uniform and total elongations decrease sharply. These changes may be associated with significant increase in the Peierls stress below 190K, which is peculiar to bcc metals.

Reference

1) Kurishita, H. Yamamoto, T. Nagasaka, T..Nishimura, A. Muroga, T. and Jitsukawa, S., Mater. Trans., **45** (2004) 936-941.
2) ASTM E1820-99a, Annual Book of ASTM Standards, (2000)