§7. Fracture Toughness Evaluation of Reduced Activation Materials with Miniaturized Specimen

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In order to evaluate the degradation of fracture toughness of thin wall structures made of reduced activation materials due to heavy irradiations with intense neutron sources such as IFMIF, it is necessary to develop technologies to measure the fracture toughness for sub-sized or miniaturized specimens of several millimeter thickness under needed test conditions. For this purpose a project entitled "Fracture toughness evaluation of reduced activation materials by miniaturized specimens" was initiated in 2000 as one of KEP. In 2000, we installed a fatigue test machine and used it to establish how to introduce a well-defined crack that meets the requirements for the fracture toughness testing of differently sized miniature bend specimens of reduced activation ferritic steels such as JLF-1, F82H and JFMS.

In this study, the tests for the determination of fracture toughness using parameters of K, J and CTOD were conducted under different test conditions to examine the applicability of each parameter to miniaturized bend specimens for the opening mode (Mode I) of loading. Tensile tests with miniaturized sheet specimens were also conducted under different test conditions. FEM analysis was made to estimate the stress and strain field around pre-crack tip until the crack starts to advance under applied load. Efforts to develop a program required for use of fracture reconstruction methods to analyze the sequence of events leading to crack initiation and propagation were made.

Four types of bend specimens and one type of tensile specimen were prepared from reduced activation ferritic steel, JLF-1. The bend specimen is single edge-notched and fatigue cracked beam loaded in three-point bending with a support span, S, equal to four times the width and has the following dimensions (the thickness, B, width, W, and length, L): 7 mm^B by 10 mm^W by 45 mm^L, 5 mm^B by 5 mm^W by 25 mm^L, 3.3 mm^B by 5 mm^W x 25 mm^L, 3.3 mm^B x 3.3 mm^W x 18.3 mm^L. The dimensions for tensile specimen are 0.5 mm^B by 4 mm^W by 16 mm^L with a gage section of 0.5 mm by 1.2 mm by 5 mm. The crack length, a_0, from the notched side to the pre-crack front was controlled to be 0.5W and the side grooves to be 0.4B. A temperature control bath, bend test fixtures with different spans and a clip gage (or displacement gage) were specially designed to perform the fracture toughness test at and below room temperature for the miniaturized bend specimens. The clip gage was seated on an attachable knife edge with 1 mm thick that had been cemented on the notched side. The fracture toughness tests were conducted at room temperature and 77K at cross-head speeds of 0.013 and 13 mm s^{-1}. For the test for J_{IC}, a program for unloading compliance method with single bend specimen was developed. Tensile tests were also conducted at room temperature and 77K at initial strain rates of $1x10^{-3}$ and $1 \times 10 s^{-1}$. For FEM analysis, two dimensional plane strain analysis with 1274 8-node elements was used assuming that the crack-tip radius is 1 μm.

It is found that the COD test is applicable in a wide test temperature and strain rate range for any types of bend specimens mentioned above. Application of FEM analysis to the data obtained from the specimen of 5 mm^B by 5 mm^W by 25 mm^L and 3.3 mm^B by 5 mm^W x 25 mm^L reproduces well the measured load-clip gage displacement curves at room temperature and 77K providing that assumed values of equivalent thickness are chosen. The assumed values agree well with the thickness for plane-strain fracture to occur, which is easily determined from fracture surface examination by SEM. This success of FEM analysis for fracture toughness test results on miniaturized bend specimen is very important because it may allow us to solve the difficult problem of size effect of fracture toughness of structure materials.

The effect of strain rate on fracture toughness of JLF-1 is not significant, but the effect of test temperature is significant. According to J_{IC} test result on the specimen of 7 mm^B by 10 mm^W by 45 mm^L, at room temperature JLF-1 has a high fracture toughness value, approximately 200-230 kJ/m^2. However, at 77K JLF-1 exhibits significant embrittlement and gives K_{IC} values that are as low as 13 ~ 16 $MPam^{1/2}$ regardless of specimen size and satisfy the criterion of B, $W\text{-}a > 2.5(K_{IC}/\sigma_{ys})^2$.

We have almost developed a new program for fracture and reconstruction methods to be used in this project, which is based on the program of assemble.c originally developed for UNIX by K. Edsinger.