§15. Small Specimen Test Techniques
–Fracture Toughness (CT)–

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In the present study, fracture toughness of the reduced activation ferritic steel (JLF-1) is evaluated with applying small specimen test techniques to the fracture toughness, J_{IC}, measurement in order to establish appropriate evaluation method towards IFMIF materials irradiation experiments [1].

The material used in this study was the JLF-1LN steel (JLF-1 JOYO-heats). Four different sizes of compact tension (CT) specimens were fabricated: 1t-1CT, 1/2t-1CT, 1/2CT and 1/4CT specimens. The geometries of 1t-1CT, 1/2CT and 1/4CT specimens are similar figure. The specimens were fatigue pre-cracked before testing to a ratio of the crack length to specimen width (a/W) of 0.5, and then side-grooved by 25% (25% SG) of their thickness and the root radius was 0.1 mm. The fracture toughness tests were carried out at room temperature referring to the ASTM E1820-99a by means of the unloading compliance method.

The dependence of the fracture toughness on a) specimen thickness and b) ligament size is shown in Fig. 1. The J_Q values obtained for the 1t-1CT and 1/2t-1CT specimens were 425 and 560 kJ/m^2, respectively. The fracture toughness increased as decreasing in the specimen thickness. On the other hand, the fracture toughness decreased when the specimens were miniaturized while keeping the similar figure, resulting that the J_Q values for the 1/2CT and 1/4CT specimens were 382 and 300 kJ/m^2, respectively.

The weibull distribution analysis of the measured fracture toughness is necessary for dealing with a variability in the obtained data such as J_Q. The parameter m (shape parameter) is determined from the slope of the line. For each line, the values were ranging from 10 to 14, suggesting that fracture toughness data with high reliability is obtained even for the miniaturized 1/4CT specimens.

The fracture toughness increased as decreasing in the specimen thickness. Two of the possible explanations of the above results are as follows.

1) It is considered that the plane stress state becomes predominant as specimen thickness decreases, and the plastic zone size at the crack tip increases near specimen side surfaces. Since the energy spent on the plastic diformation increases, the fracture toughness increased.

2) The crack growth occurs at the weakness part of crack front (weakest-link theory), it is considerd that the fracture probability increases as the specimen thickness increses, and the 1t-1CT specimen presented a low fracture toughness. However, since the weibull distribution form of the 1t-1CT were similar to 1/2t-1CT, it is considered that the first factor

is more predominant in the specimen thickness effect on the fracture toughness obtained for the above two type of specimens.

According to the slip-line field analysis for the static loading [2], the plastic zone size at the crack tip is described by $2(J/\sigma_{ys})$ where σ_{ys} is the yield stress of the material. The value obtained for JLF-1 is around 1.6mm for standard size specimen. It can be considered that almost half of the ligament length was occupied by the plastic zone in the 1/4CT specimen, while there was enough ligament length in the 1CT specimen. When the specimen size becomes extremely small like 1/4CT size, the ligament size becomes too small to suppress gross yielding, resulting in flow instability and decrease in the J_Q values for the smaller specimens.

Since the first wall thickness is estimated to be less than 5 mm for ferritic steel-water blanket system, the obtained fracture toughness values of the first wall were always invalid before and probably after irradiation. It is demanded that new valid/invalid criterion can be established for thin specimens to provide a valid database, if necessary, of fracture toughness of fusion blanket structural materials.

References

1) H. Ono, R. Kasada, A. Kimura, J. Nucl. Mater., (2004) in press.

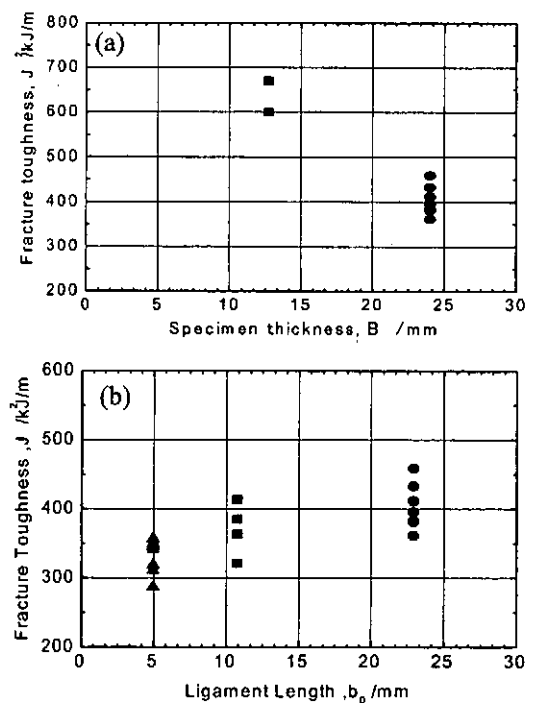2) J. R. Rice, Trans. ASME, J. Appl. Mech. (1968) 379-386.

Fig. 1. Effect of specimen size on fracture toughness J_Q
   (a) Specimen thickness dependence
   (b) Ligament size dependence