§7. Standardization of the Fracture Toughness Test Method by Round Bar with Circumferential Notch

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1. Introduction

Standardized test methods of plain strain fracture toughness K_{Ic} and elastic-plastic fracture toughness J_{Ic}[1] are time-consuming and expensive. On the other hand, a convenient new test method, named J evaluation on tensile test (JETT), has been proposed to evaluate the fracture toughness of the tough materials.[2-3] Since JETT is not standardized yet, the size of JETT specimen should be carefully selected. Therefore the FEM calculations for the comparison of the strain constraint around the notch or crack tip around both specimens are needed before the experiments. In this research, the diagrams showing the effective JETT specimen sizes as a function of a work-hardening exponent and a work-hardening coefficient were tried to be made.

2. FEM calculation

Substituting various n and α in the following Ramberg-Osgood equation, normalized stress-strain curves of various materials can be approximately simulated.

$$\left(\frac{\varepsilon}{\varepsilon_{0.2}}\right)=\left(\frac{\sigma}{\sigma_{0.2}}\right)+\alpha\left(\frac{\sigma}{\sigma_{0.2}}\right)^n$$

In this research, the effective specimen sizes for fracture toughness test of representative 9 kinds of normalized stress-strain curves, n = 3, 5 and 20 for each α = 5, 10 and 20 were discussed. Q-factor is the one of the indexes of the strain constraint around a notch or crack tip. It shows the difference of the magnitude of the open mode stresses between with a JETT specimen and the standardized specimen at the same distance from a tip on the ligament. In this research, if Q at critical J is 0±0.1, the obtained critical J by JETT is defined to be valid. On the other hand, MAX-location is the position on the ligament where the maximum open mode stress is generated. If the MAX-location is the center axis of the round bar, not the fracture from a tip but the tensile fracture caused by growing voids in the center can be suspicious. In such a case, the necessary condition for a fracture toughness test does not satisfy. Therefore both Q-factor and MAX- location limit the specimen size of JETT.

3. Results and discussion

Q-factor and MAX-location of the specimen with stress-strain curve of n=20, α=10 and dimension of a/R = 4.5mm / 8mm = 0.5625 is shown in Fig.1. Lower bound of the Q (Q = -0.1) and the transition point of MAX-location from around a tip to the centre of the specimen limit the effective critical J, 42 kJ/m^2 ≦ J ≦ 92 kJ/m^2. If a critical J obtained from a fracture toughness experiment (=J_{in}) with the dimension of a/R = 4.5mm / 8mm is within this range, obtained J_{in} can be defined to be the toughness corresponding to standardized test, J_C. If it is out of the range, the size of specimen has to be reselected. Similarity law in fracture mechanics says, if the stresses generated at the same distance from a tip in the similar two specimens (the similarity ratio n) are same, the ratio of J of both specimens is n. In practice, the effective critical J, 21 kJ/m^2 ≦ J ≦ 48 kJ/m^2 is obtained by the same FEM calculation with half size specimen, a/R = 2.25mm / 4mm. Fig.2 shows the effective specimen size for fracture toughness test. Considering the proportional relationship between specimen size (radius R) and J_{in}, the abscissa is defined to be normalized specimen size. For example, the material with n=20, α=10 and a/R = 0.5625 needs normalized specimen size, 25≦ $R\sigma_0/J_{in}$≦58. The condition for specimen size with the other materials, n=3 and 5, are also shown in Fig.2. This limitation is the same one as is defined with standardized CT specimen, B, b_0 > $25J_{in}/\sigma_0$, where B and b_0 are size parameters of the specimen.

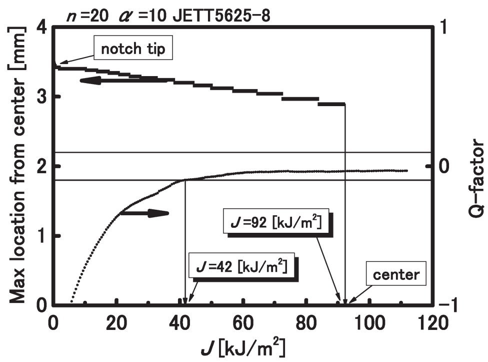

Fig.1 Q-factor and MAX location VS. J

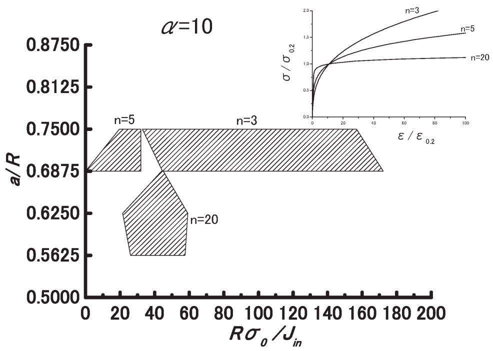

Fig.2 Effective specimen size to obtain J_C