§13. 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} are time-consuming and expensive. On the other hand, a convenient new test method, named J evaluation on tensile test (JETT) of round bar with circumferential notch, has been proposed to evaluate the fracture toughness of the tough materials. From our studies of strain constraint, the valid critical J value of some materials can be obtained by JETT specimens but that of the other materials cannot. Every material of JETT specimen needs the special FEM calculation to evaluate its strain constraint, while that of standardized specimen has the single equation evaluating the strain constraint (plane strain condition). In this research, the strain constraints of JETT specimens needed for valid critical J were calculated and the substitute equation for the single equation of standardized specimen or corresponding conditions were tried to find.

2. Normalized stress-strain curves

The following equation called Ramberg-Osgood equation approximately shows normalized stress-strain curves of various elastic-plastic materials.

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

where $\sigma_{0.2}$ is the 0.2% proof stress, $\varepsilon_{0.2}=\sigma_{0.2}/E$ with E being the Young's modulus, n is the strain hardening exponent and α is a material constant. The calculated strain constraint of a material with a pair of (α, n, $\sigma_{0.2}$) is effective only for the material. However if both applied stress and calculate solution are normalized by $\sigma_{0.2}$, the normalized solution is effective for various material with the same (α, n).

3. Equivalent strain constraint to plane strain state

The previous year's calculations of the equivalent strain constraint to plane strain and evaluations of the stress distribution on the ligament were conducted to materials with various normalized stress-strain curves. The single equation evaluating the plane strain condition of standardized specimens is

$$B \text{ or } b_0 > 25\left(J_Q/\sigma_{0.2}\right)$$

where B is the specimen thickness, b_0 is the initial ligament length and J_Q is the obtained critical J. This equation compares $J_Q/\sigma_{0.2}$, a plastic zone size parameter, and the specimen size. This comparison depends only on the proof stress.

Fig.1 shows a plastic zone size parameter of JETT specimen with a/R=0.625 and R=8mm. The values at which the strain constraint is equivalent to plane strain are plotted. However the open symbols in the figure need to be excluded because of invalid stress distribution on the ligament as a toughness test. Therefore a valid critical J of a material with n=2 and α>0.4, remarkable work hardening, and n=20 and α=0.4, nearly elastic-perfect plastic, cannot be obtained by this specimen.

Fig.2 shows the relationship between a plastic zone size parameter and a specimen size. If a material with α=4 and $5 < n < 10$, a plastic zone size parameter depends much on a radius (specimen size). Therefore making the specimen size bigger or smaller enables to generate the optimum strain constraint around a notch of JETT specimen. This character is needed for repeating tests by updating specimen size until the valid critical J is obtained.

The figures like Fig.1 and Fig.2 are proposed to evaluate the strain constraint equivalent to plane strain condition and validity of the obtained critical J of a JETT specimen.

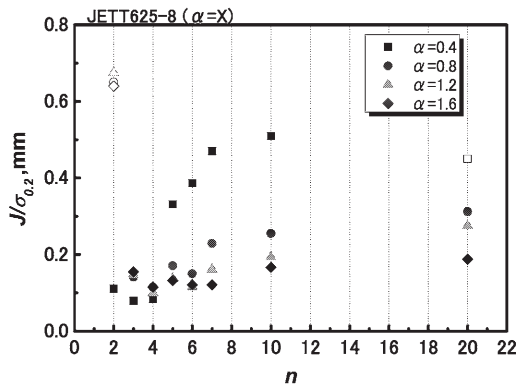

Fig.1 A plastic zone size parameter at which the strain constraint is equivalent to plane strain.

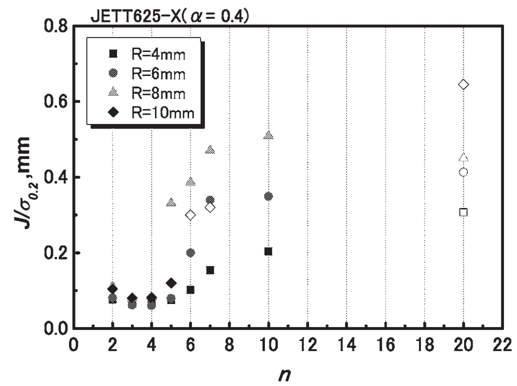

Fig.2 The relationship between a plastic zone size parameter and a specimen size