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Assessment of Constraint Effects based on Local Approach

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1. Introduction

Traditional fracture mechanics has been used to ensure a structural integrity, in which the geometry independence is assumed in crack tip deformation and fracture toughness. However, the assumption is applicable only within limited conditions. To address fracture covering a broad range of loading and crack geometries, two-parameter global approach and local approach have been proposed.

The two-parameter global approach can quantify the load and crack geometry effects by adopting T-stress or Q-parameter but time-consuming and expensive since lots of experiments and finite element (FE) analyses are necessary. On the other hand, the local approach evaluates the load and crack geometry effects based on damage model. Once material specific fitting constants are determined from a few experiments and FE analyses, the fracture resistance characteristics can be obtained by numerical simulation.

The purpose of this paper is to investigate constraint effects for compact tension (CT) specimens with different in-plane or out-of-plane size using local approach. Both modified GTN model and Rousselier model are adopted to examine the ductile fracture behavior of SA515 Gr.60 carbon steel at high temperature. The fracture resistance (*J-R*) curves are estimated through numerical analysis, compared with corresponding experimental results and, then, crack length, thickness and side-groove effects are evaluated.

2. Damage models and calibration

2.1 Damage models

The effectiveness of two damage models was addressed by the authors already [1]. In this paper, just key features of damage models are recalled as follows:

Modified GTN Model. Gurson model [2] was used to analyze plastic flow in a porous medium by assuming that materials behave as a continuum. It was modified by other researchers, then, the yield surface became as

$$\Phi = \frac{3}{2}\frac{S_{ij}S_{ij}}{\sigma_{YS}^2} + 2f\cosh\left(\frac{3}{2}\frac{\sigma_m}{\sigma_{YS}}\right) - (1+f^2) = 0 \qquad (1)$$

where, f is the void volume fraction, S_{ij} is the deviatoric stress defined as $S_{ij} = \sigma_{ij} - \sigma_m \delta_{ij}$. Also, Tvergaard and Needleman [3, 4] modified the original model by replacing f to an effective void volume fraction f^*:

$$f^* = \begin{cases} f & \text{for } f \le f_c \\ f_c - \dfrac{f_u^* - f_c}{f_F - f_c}(f - f_c) & \text{for } f > f_c \end{cases} \qquad (2)$$

where, f_c, f_u^* and f_F are the material specific fitting constants with regard to void growth, coalescence and failure respectively.

Rousselier model. This model [5] defines the yield surface as a function of hydrostatic stresses:

$$\Phi = \frac{\sigma_{eq}}{\rho} + D \cdot \sigma_1 \cdot f \cdot \exp\left(\frac{\sigma_h}{\rho\sigma_1}\right) - R(\varepsilon_{eq}^P) = 0 \qquad (3)$$

where, σ_1 and D are fitting constants, σ_{eq} is equivalent von Mises stress, σ_h is hydrostatic stress, ρ is material density and $R(\varepsilon_{eq}^P)$ represents work-hardening law. In order to apply Rousselier model to specific material, the σ_1, D and initial void volume fraction (f_0) have to be determined. Rousselier suggested that the value of σ_1 as 2/3 times of yield strength and the value of fitting constant D as 1.5~2.0.

2.2 Mechanical property and material fitting constant

The mechanical properties of SA515 Gr.60 carbon steel was obtained from tensile tests at 316℃. The yield strength was 155MPa, tensile strength was 452MPa, Ramberg-Osgood parameters (α, n) were 1.08 and 6.02 respectively. The relevant material specific fitting constants were quoted from reference or calibrated from three dimensional FE analyses of 1T-CT standard specimen [6] such as f_0=0.0031, f_c=0.019, f_f=0.20, q_1=1.96, q_2=0.781, D=2.0 and σ_1=430MPa.

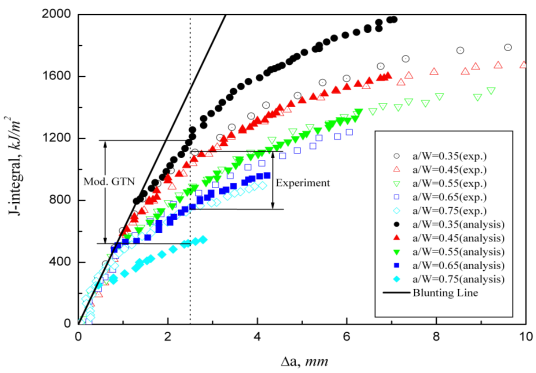
3. Estimation of J-R curves

3.1 FE analyses

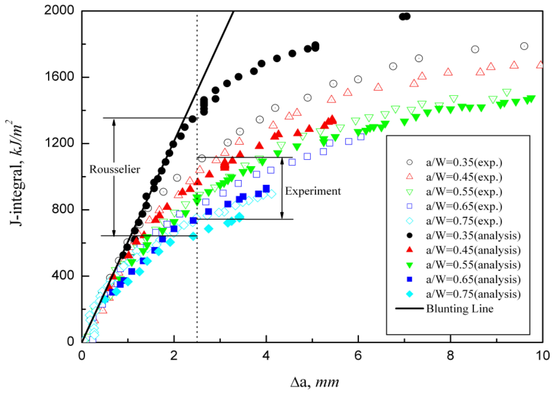
Several CT specimens were analyzed to investigate the crack length, thickness and side-groove effects. ABAQUS 6.5-1 and user subroutine (UMAT) incorporating two damage models were used for numerical simulation.

The cell size around crack tip was set to 250μm and three dimensional 8-node solid element (C3D8) was adopted. A crack extension was simulated by element death method in which Young's modulus becomes zero and load carrying capacity is vanished.

From the FE analyses, *J-R* curves were estimated for CT specimens with various crack length (a_0/W= 0.35, 0.45, 0.55, 0.65 and 0.75), various thicknesses (12.7, 25.4, 38.1 and 50.8 mm) and with/without side-grooves.

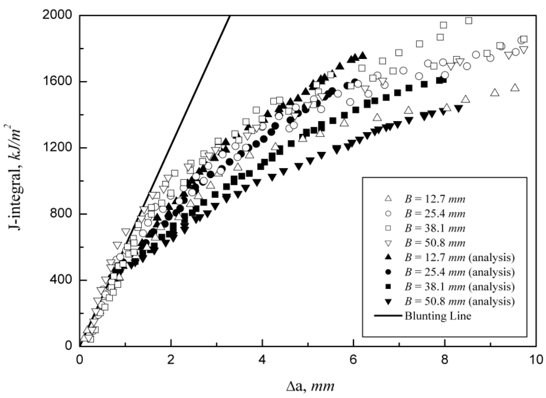


(a) Modified GTN model

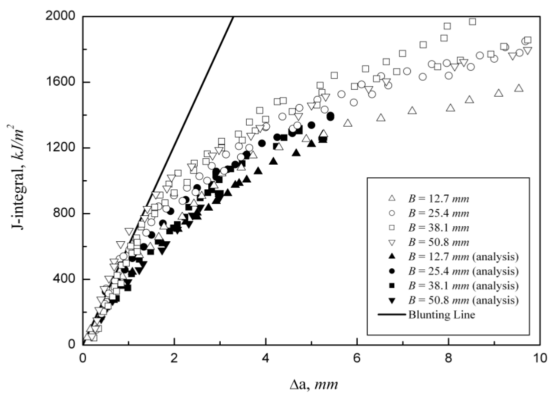


(b) Rousselier model

Fig. 1 *J-R* curves of CT specimens with various crack length



(a) Modified GTN model



(b) Rousselier model

Fig. 2 *J-R* curves of CT specimens with various thicknesses

3.2 Estimation results and discussion

Fig. 1 depicts *J-R* curves of CT specimens with various crack length. The FE analysis results combined with damage models gave good consistency with test results in case of standard cracked specimens (a_0/W= 0.45~0.65). Fig. 2 depicts *J-R* curves for varying thicknesses. The effectiveness of local approach was sustained for thinner and standard specimens. However, in contrast to FE analysis results, there was a little effect in case of test results for thicker specimens. Besides, the *J-R* curves of CT specimens without side-grooves were estimated higher than the ones with side-grooves and the analysis results agreed well with the test data.

In general, the estimated *J-R* curves showed good applicability except for shallow and long cracked specimens (a_0/W=0.35, 0.75) or thicker specimens (*B*=38.1, 50.8). The main reason is believed that current damage models have some limitations to simulate free surface behavior, which will be further investigated. In addition, during the simulation process, the values of *J*-integral were estimated from the area of P-δ curves and the crack extension was determined by aforementioned element death method. And, with regard to blunting phenomenon before crack initiation, the concept of construction line described in ASTM standard was used because it can not be considered by the local approach.

4. Conclusion

The *J-R* curves were estimated by using local approach for various CT specimens made from SA515 Gr.60 carbon steel. In spite of some limitation, it was proven that the numerical simulation is a promising tool for prediction of ductile fracture and can be utilized for quantifying constraint effects related to varying crack length, thickness and side-grooves.

References

[1] Chang, Y.S., Lee, T.R., Choi, J.B. and Kim, Y.J., Assessment of Geometry Independent Fracture Resistance Characteristics based on Local Approach, Key Engineering Materials, Vols. 297-300, pp. 2403-2409, 2005.

[2] Gurson, A.L., Continuum Theory of Ductile Rupture by Void Nucleation and Growth: Part 1-Yield Criteria and Flow Rules for Porous Ductile media, Journal of Engineering Material and Technology, Vol. 99, pp. 2-15, 1977.

[3] Tvergaard, V., On Localization in Ductile Materials Containing Spherical Voids, International Journal of Fracture, Vol. 18, pp. 237-252, 1982.

[4] Tvergaard, V. and Needleman, A., Analysis of the Cup-Cone Fracture in a Round Tensile Bar, Acta Metallurgica, Vol. 18, pp. 157-169, 1982.

[5] Rousselier, G., Les modèles de rupture et leurs possibilitès acuelles dans le cadre de l'approche locale de la rupture, International Symposium on Local Approach to Fracture, Centre de recherche 'Les Renardières',Moret-sur-Loing, 1986.

[6] Lee, T.R., Chang, Y.S., Choi, J.B., Seok, C.S. and Kim, Y.J., Prediction of Fracture Resistance Curves of Compact Tension Specimens with Various In-plane Sizes Using Local Approach, Korean Nuclear Society Spring Conference, 2005.