Mesh Size Effects on Fracture Toughness Estimation by Damage Model

Shin-Beom Choi [a], Yoon-Suk Chang [a], Young-Jin Kim [a*], Min-Chul Kim [b] and Bong-Sang Lee[b]
[a]*School of Mechanical Engineering,Sungkyunkwan Univ., 300 Chunchun-Dong, Suwon, Gyeonggi-do 440-746*
[b]*Nuclear Material Technology Division, Korea Atomic Energy Research Institute, 150 Dukjin-dong, Yuseong, Daejon 305-330*
[*]*Corresponding author: yjkim50@skku.edu*

1. Introduction

The objective of this paper is to investigate mesh size effects on fracture toughness of SA508 carbon steel by damage model. To achieve this goal, a series of finite element analyses are carried out for CT (compact tension) and PCVN (pre-cracked V-notch) specimens. And Weibull stress model are adopted to derive toughness scale diagram. Finally, toughness scale diagram, which considered crack-tip mesh size effects, is derived from comparing estimated fracture toughness data between CT and PCVN specimens under -60°C and -80°C.

2. Computational Damage Model

In this section material properties, FE model and Weibull stress model, which are necessary to verify mesh size effect, are explained.

2.1 Material Properties

Tensile tests were carried out for SA508 carbon steel at -60°C and -80°C as indicated in Fig. 1. To describe plastic behavior of material, the temperature-dependent power law relationships were derived using Eq. (1). Table I represents Ramberg-Osgood parameters as inputs for finite element analyses and relevant mechanical properties are Young's modulus of 196GPa, Poisson's ratio of 0.3 and Yield stress of 502MPa.

$$\frac{\varepsilon}{\varepsilon_0} = \frac{\sigma}{\sigma_0} + \alpha\left(\frac{\sigma}{\sigma_0}\right)^n \tag{1}$$

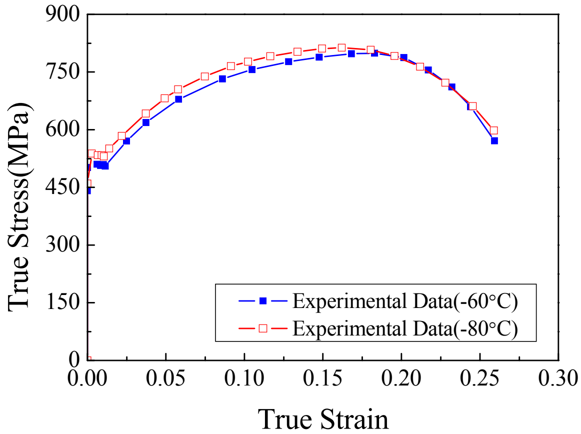

Fig. 1. Stress-strain curves of SA508 carbon steel

Table I: Ramberg-Osgood parameters of SA508 carbon steel

Temperature	α	n
-60°C	2.43	7.03
-80°C	2.41	6.77

2.2 Finite Element Model

The CT and PCVN specimens as depicted in Fig. 2 were modeled and analyzed. The quarter model was generated for 1T-CT, 1/2T-CT and 1/3T-CT specimens, which consists of 19,525 nodes and 16,640 elements. And the quarter model of 10x10mm, 5x5mm and 3.3x3.3mm PCVN specimens consists of 11,594 nodes and 9,740 elements. To verify optimized meshing, both the same and proportional meshes were generated near the crack-tip while element numbers are depended on the thickness and ligament of specimens.

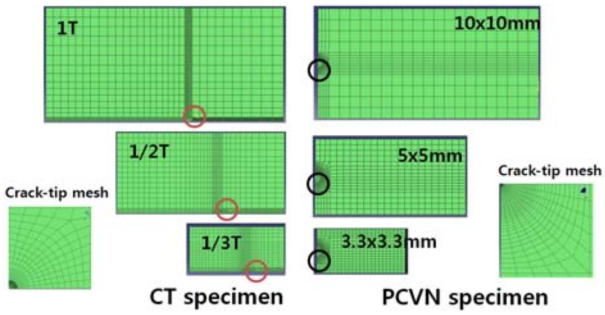

Fig. 2. FE models of CT and PCVN specimen under the same mesh size at crack-tip

2.3 Weibull Stress Model

The Weibull stress model, which is based on the weakest link theory and two parameters statistics, has been proposed [1-3]. This model is used for elastic-plastic structural assessment and damage criteria. The Weibull stress is calculated as follows:

$$\sigma_W = \left[\sum_{i=1}^{n_e} (\sigma_{1,i}^m)\frac{V_i}{V_0}\right]^{1/m} \tag{2}$$

where, n_e denotes number of elements which exceed the reference stress, V_0 is a reference volume prescribing near the crack-tip area and V_i is the volume of ith material unit in the crack-tip plastic zone experiencing a maximum principal stress σ_1.

To apply the Weibull stress model, parameters such as m and σ_u are valued using authors' previous research in Table II [4].

Table II: Weibull parameters m and σ_u

Temperature	m	σ_u
-60°C	22.4	1359
-80°C	19.4	1238

3. Fracture Toughness Estimation

3.1 FE Analysis Results

Fig. 3 shows σ_W-J curves from FEA results of same mesh size at crack-tip. At the given Weibull stress 1200*MPa*, *J*-integral of PCVN specimen is two times as large as *J*-integral of CT specimen. It means that CT specimen is easier to initiate cleavage fracture than the relatively thin PCVN specimen. This difference can be adjusted, e.g., via a toughness scale diagram.

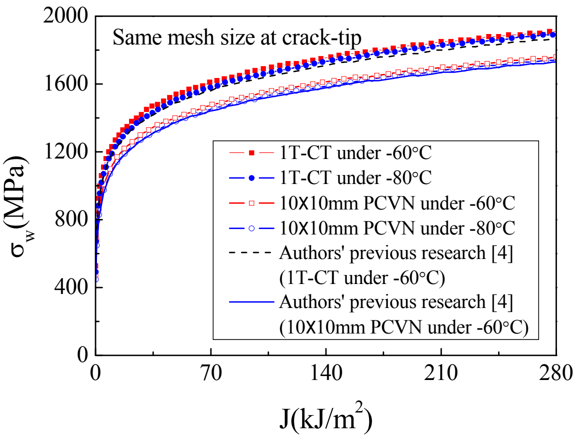

Fig. 3. Modified σ_W-J curves in accordance with varying temperatures

The maximum difference of *J*-integral between authors' previous research [5] and the present work was 17 % at a given Weibull stress level of 1500*MPa*, for instance, which can affect the failure characteristics.

3.2 Toughness Scale Diagram

Fig. 4 represents several toughness scale diagrams, in which the one obtained by employing the proportional mesh is more conservative and scattered than that of the same mesh due to constraint effects and different reference volume sizes affecting on fracture toughness. As a result, thickness variation of PCVN specimens does not affected on toughness scale diagram under the same mesh size at crack-tip.

4. Conclusions

In this paper, the cleavage fracture evaluation based on local approach was carried out for SA508 carbon steel at -60°C and -80°C to derive a specific toughness scale diagram and following conclusions are derived:

(1) The maximum difference between proportional and same mesh size at crack tip was 17%. So, mesh size effects must be considered to exactly evaluate fracture toughness.
(2) Thickness variation of PCVN specimen did not affect on toughness scale diagram which was derived from the same mesh size at crack-tip.

This result can be used to define the failure characteristics of SA508 carbon steel in cleavage fracture temperature region.

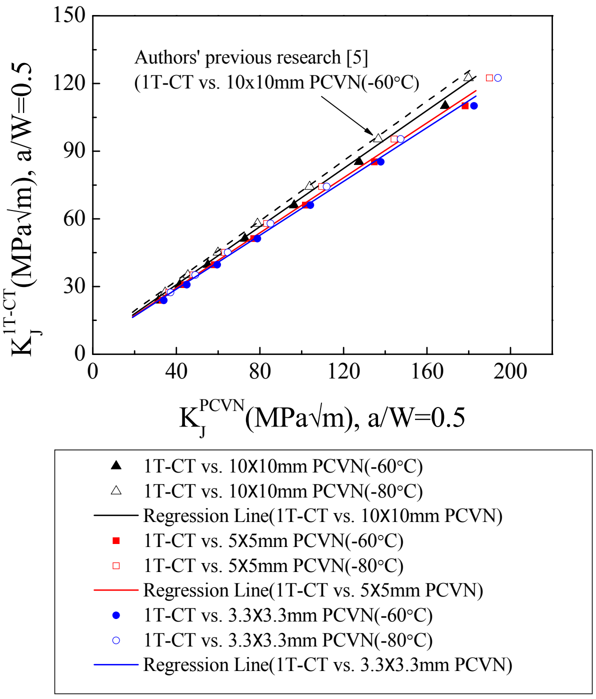

Fig. 4. Modified toughness scale diagram

REFERENCES

[1] F.M. Beremin, A Local Criterion for Cleavage Fracture of a Nuclear Pressure Vessel Steel, Metallurgical Transactions, Vol.14A, pp. 2277-2287, 1983.
[2] F. Minami, A Brűchner-foit, D. Munz and B. Trolldenier, Estimation Procedure for the Weibull Parameters used in the Local Approach, International Journal of Fracture, Vol.54, pp. 197-210, 1992.
[3] X. Gao, R.H. Dodds Jr., R.L. Tregoning, J.A. Joyce and R.E. Link, A Weibull Stress Model to Predict Cleavage Fracture in plates containing surface cracks, Fatigue and Fracture of Engineering Materials and Structures, Vol.22, pp. 481-493, 1999.
[4] H.O. Ko, Y.S. Chang, Y.J. Kim, M.C. Kim and B.S. Lee, Fracture Toughness Estimation and Constraint Effect Quantification by Weibull Stress Model, Transactions of the Korean Society of Pressure Vessels and Piping, Vol.2, No. 2, pp. 31-38, 2006.
[5] Sungkyunkwan University, Analysis Technology of Local Fracture Behavior Based on Finite Element Method, KAERI/CM-999/2006, 2006.