LOCAL APPROACH TO CORRELATE CLEAVAGE FRACTURE TOUGHNESS WITH MICROSTRUCTURE OF STEEL

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Abstract

This study proposes a new fracture model to correlate cleavage fracture toughness with microstructure of steel having bainitic structure with/without M-A constituent based on the Local Approach. In this model, a new fracture parameter to predict fracture toughness is derived through the proposal of microstructural characteristic of the material to control fracture toughness and on the basis of weakest link theory assumed Griffith crack. The material properties required for applying the fracture model are microstructural properties, those are 1) representative volume and 2) maximum size distribution of micro-crack nuclei, 3) mechanical properties and 4) effective energy release rate of matrix material. The applicability of the theoretical fracture model is demonstrated by experiments for upper bainitic steel with different microstructural morphology. This model can correlate materials properties which are microstructural and mechanical properties with fracture toughness.

1. Introduction

Based on a local approach to describe fracture toughness from the viewpoint of microscopic mechanism of fracture, the Weibull stress concept has been proposed by Beremin. This concept assumes microcracks such as carbides as the source of brittle fracture initiation site and tries to evaluate the brittle fracture resistance including its probabilistic characteristics based on the weakest link model. However, this model can not sufficiently describe the effect of microstructures of materials on fracture toughness. This study propose a fracture model that can quantitatively predict the fracture toughness of high strength steels with bainitic microstructures, including their variability, based only on the microstructural and stress-strain properties of the material.

2. New fracture model

In this model, the microstructural unit volume that characterizes the orientation distribution of the micro-crack nucleus was considered to be one of the microstructural factors controlling fracture, and this unit volume was incorporated as the representative volume V_{R}. The maximum size of the micro-rack nucleus that contributes to fracture in the V_{R} was considered, and the microstructure of the material was characterized by the size distribution based on extreme value statistics. As schematically illustrated in Fig. 1, the microstructural properties of the upper bainite were characterized by the V_{R} and the extreme value distributions of micro-crack nucleus size obtained by microstructural observation. By expressing the extreme value distribution of the micro-crack nucleus size as an exponential type III maximum asymptotic distribution with an upper limit value a_{lim} and applying the weakest link mechanism of fracture, a new fracture parameter λ_{W} was derived as shown in Eq. (1), and the cumulative fracture probability of specimens evaluated with this λ_{W} follows a two-parameter Weibull distribution.

$$F = 1 - \exp\left\{-\left(\frac{\lambda_{\mathrm{W}}}{\lambda_u}\right)\right\}, \qquad \begin{cases} \lambda_{\mathrm{W}} = \left[\dfrac{1}{V_{\mathrm{R}}}\displaystyle\int_V \left\{1 - \left(\dfrac{\sigma_{\min}}{\sigma}\right)^2\right\}^{\beta} dV\right]^{1/\beta} \\ \lambda_{\mathrm{u}} = \alpha / a_{\mathrm{lim}} \end{cases} \tag{1}$$

Based on this model, the fracture toughness, including the lower limit and probabilistic characteristics, can be predicted by calculating the stress distribution near the crack tip using a three-dimensional elastoplastic FEM analysis of a fracture toughness specimen, as long as the following four material properties are obtained.

1) Representative volume V_R.
2) Extreme value distribution of micro-crack nucleus size contributing to fracture in V_R:

$$P_{III}(A) = \exp\left\{-\left(\frac{a_{lim} - A}{\alpha}\right)^{\beta}\right\}$$

3) Stress-strain curve of the material at the temperature of interest: *s-e* curve
4) Effective energy release rate of matrix material: G_{cr}

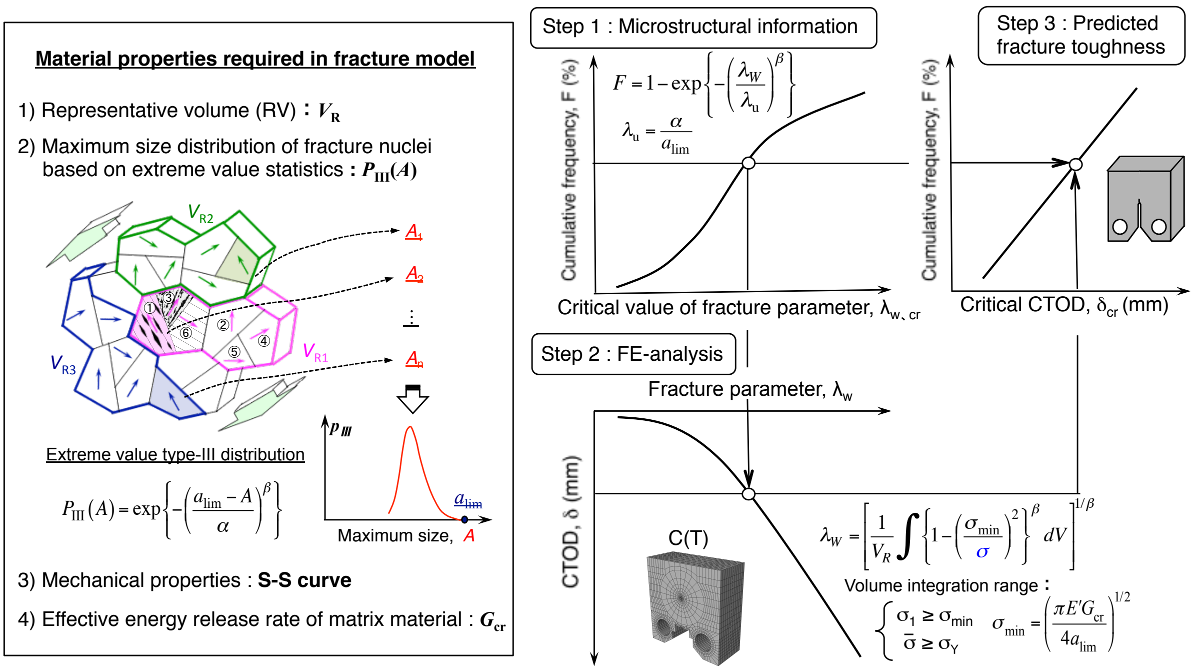

Figure 1 – Procedure for predicting fracture toughness by means of proposed fracture model based on the Local Approach, and material properties that can be correlated with fracture toughness

3. Results

In the experiments, three-type of upper bainitic steel with different microstructures, which has the same chemical composition, were used. Fracture toughness tests for those three steels were conducted at -110°C. The three steels exhibited different cumulative distributions of fracture toughness depending on the microstructure of each steel. These fracture toughness distributions were predicted from the material properties based on the proposed fracture model. The predicted cumulative distributions of the fracture toughness for these steels were in good agreement with experimental results.

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