APPLICATION OF A NOVEL UNIFIED PARAMETER ON CHARACTERIZING IN-PLANE AND OUT-OF-PLANE CRACK-TIP CONSTRAINTS FOR AL7075 T651 SEN(B) SPECIMENS

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Abstract

Crack-tip constraint can have a significant effect on fracture toughness. A loss of crack-tip constraint can cause an increase in fracture toughness. In this paper, a novel unified constraint parameter λ based on the plastic strain energy was proposed to quantify the crack-tip constraint level. The application of this parameter for assessing the in-plane and out-of-plane constraints of Al7075 T651 alloy SEN(B) specimens was investigated with a series of fracture bending experiments and numerical modelling.

1. Introduction

Crack-tip constraint can have a significant effect on fracture toughness. A high constraint component has a lower fracture toughness, while a low constraint component shows a higher toughness at fracture. Therefore, to make a less conservative structural integrity assessment to potentially reduce costly repair and replacement decisions for plant operators, it is important to quantify the constraint level and correlate it with fracture toughness variation.

The crack-tip constraint is defined as the resistance of a structure against crack-tip plastic deformation. It can be divided into in-plane and out-of-plane constraints. The in-plane constraint is affected by the dimension in the growing crack direction which is the ligament length or the crack length, while the out-of-plane constraint is affected by the dimension parallel to the crack plane which is the specimen thickness. Currently, there are many parameters that are used to characterize in-plane constraint and out-of-plane constraint separately. For example, T-stress and Q were used to assess the in-plane constraint level, and T_Z works as an out-of-plane constraint. However, they are difficult to quantify the combined effects of both constraints in real cases. Thus, some unified constraint parameters were proposed to characterize such combined effects, such as the Anderson–Dodds method, φ and A_P. This paper describes a novel unified constraint parameter λ based on the crack-tip plastic strain energy. A large number of three-point bending tests on Al7075 T651 alloy SEN(B) specimens with different geometries at room temperature and a series of numerical modelling were conducted to validate this measurement method.

2. Results

Brocks and Schmitt stated the crack-tip constraint is the resistance of a structure against crack-tip plastic deformation. Based on this definition, a novel unified constraint parameter λ is proposed in this study.

Within a finite element context, assume there are N elements around the crack tip reaching to yielding. For these elements, their total plastic strain energy causing plastic deformation, $U_{plastic}$, can be expressed as the difference between their total deformation strain energy, U_{total}, and elastic deformation strain energy, $U_{elastic}$:

$$U_{plastic} = U_{total} - U_{elastic} = \sum_{i=1}^{N} (\int_0^{\varepsilon_i} \sigma V_i d\varepsilon - \frac{\sigma_i^2}{2E} V_i) = \sum_{i=1}^{N} \left(\int_0^{\varepsilon_i} \sigma d\varepsilon - \frac{\sigma_i^2}{2E} \right) V_i \quad (1)$$

Where σ is the stress, ε is the strain, V_i is the volume, and E is Young's modulus. Due to the complex nature of the stress distribution in the crack-tip field, the equivalent stress σ_{eq} and the equivalent strain ε_{eq} are applied in the calculation, which makes Eq. (1) become as follows:

$$U_{plastic} = \sum_{i=1}^{N} \left(\int_0^{\varepsilon_i} \sigma_{eq} d\varepsilon_{eq} - \frac{\sigma_{eq}^2}{2E} \right) V_i \quad (2)$$

Considering both in-plane and out-of-plane constraints are mainly affected by the specimen geometry, a factor *1/Bb*, where *B* is the specimen thickness and *b* is the distance between the crack tip and the surface that directly faces the crack tip, is introduced into Eq. (2) to form a unified constraint parameter λ:

$$\lambda = \frac{U_{plastic}}{Bb} \quad (3)$$

With a series of 3-point bending tests and numerical modelling on the SEN(B) specimens which have different thicknesses and crack lengths, the results of parameter λ for all specimens at fracture were calculated with Eq. (3) and are shown in Fig. 1. It is found that the *J*-integral increases with the decrease of thickness *B* (out-of-plane constraint) and *a/W* ratio (in-plane constraint). The specimen with large thickness and deep crack (*B*=30mm, *a/W*=0.375) has the lowest fracture toughness, while the specimen with small thickness and shallow crack (*B*=5mm, *a/W*=0.075) has the highest fracture toughness. The value of parameter λ can be affected by thickness as well as crack length, indicating the parameter λ is sensitive to both in-plane and out-of-plane constraints. Fig. 1 also illustrates the trend that the lower constraint level specimen has a larger parameter λ and a high-order relationship can be obtained between the fracture toughness and parameter λ.

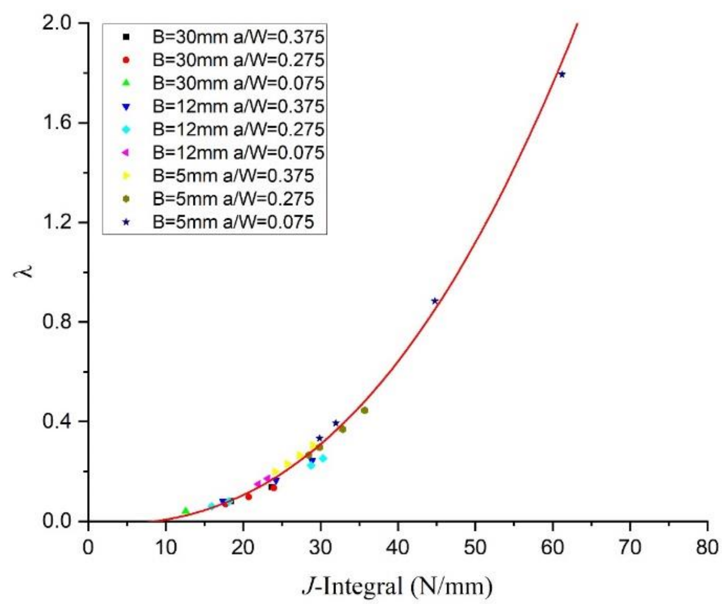

Fig. 1 – Results of parameter λ for Al7075 T651 SEN(B) specimens with different geometries.

3. Conclusions

The unified constraint parameter λ based on the plastic strain energy can characterize both in-plane and out-of-plane crack-tip constraints for Al7075 T651 SEN(B) specimens with different geometries. A unified correlation can be easily found between the fracture toughness and it. Such monotonic correlation is much better to help engineers to assess a more accurate fracture toughness of a nonstandard component.

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