Fracture Toughness Scaling Model to Assess Changes in Crack-tip Constraint

ZENG CHEN – zeng.chen@bristol.ac.uk | Supervisors: Dr. Mahmoud Mostafavi1, Dr. Rob Kulka2 | University of Bristol – TWI Ltd.

Background

- Crack-tip constraint has a significant effect on fracture toughness dependent on geometries, flaws and loading configurations.
- Crack-tip constraint can be divided into in-plane and out-of-plane constraint.
- The main influence factor of
  - In-plane constraint: crack length
  - Out-of-plane constraint: specimen thickness

Research Status

- At the early stage, the constraint parameters were proposed to quantify the levels of in-plane and out-of-plane constraint, respectively. The development history can be summarized as follows:
  - Linear elastic fracture
  - Elastic-plastic fracture
  - Stress intensity factor K
  - J-integral

- In order to eliminate the limitations of above approaches in the real configuration where a complexly mixed effect of in-plane and out-of-plane constraint exists, unified measure parameters, which are equally sensitive to both constraint types and have a comparatively consistent correlation with fracture toughness, were introduced.
  - \( \sigma / \sigma_y = C \) [Anderson and Dodds]
  - \( \varphi = \frac{\Delta\varepsilon}{\Delta \varepsilon_{ef}} \) [Mostafavi et al.]
  - \( A_P = \frac{\Delta \varepsilon_{PEEC}}{\Delta \varepsilon_{ef}} \) [YANG et al.]
  - \( A_s = \frac{\Delta \varepsilon_{ef}}{\Delta \varepsilon_{ef}} \) [Xu et al.]

Aims and Objectives

- Evaluation of the effectiveness and practicability of the current approaches.
- Development of a novel method to quantify the levels of in-plane and out-of-plane crack-tip constraint.
- A unified correlation model of crack-tip constraints with fracture toughness.
- Ideally, the results of this study can be formalized into procedural updates in BS 7910 and R6 standards.

Future Work

- Complete a Python program to extract essential data from numerical modelling results and calibrate the Beremin model or RKR criterion.
- Calculate the current constraint parameters and evaluate their advantages as well as drawbacks.
- Analyze the stress and strain field around the crack tip of models.
- Introduce a novel model to quantify the effects of constraint based on previous works.
- Design and conduct fracture toughness tests to validate the model.

Methodology

- Conduction of a series of numerical modelling on the C(T) and SEN(B) specimens with various thicknesses and crack lengths by ABAQUS and Python code.
- Calibration of the local approach (Beremin model or RKR criterion) to estimate the fracture toughness of all models.
- Study of the stress and strain field around crack tip obtained from simulation to evaluate the current characterization methods and develop a novel unified constraint parameter.
- Analysis of the correlation between all parameters and numerical fracture toughness data.
- Execution of fracture toughness tests to validate the model.

Progress so far

- A detailed literature review of in-plane and out-of-plane constraint quantification methods.
- Study of Python applied in ABAQUS.
- A series of C(T) and SEN(B) specimen models with various thicknesses and crack lengths were established. The detailed geometries are as follows:

<table>
<thead>
<tr>
<th>Specimen Type</th>
<th>a/W</th>
<th>Thickness (mm)</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEN(B)</td>
<td>0.1, 0.2, 0.3, 0.4, 0.5</td>
<td>5, 10, 15, 20, 25</td>
<td>25</td>
</tr>
<tr>
<td>C(T)</td>
<td>0.5</td>
<td>25</td>
<td>1</td>
</tr>
</tbody>
</table>

- In-plane and out-of-plane directions defined for a through-thickness crack in a general body.
- Crack-tip constraint has a significant effect on fracture toughness.
- Three-parameter and out-of-plane crack-tip constraint.
- Two-parameter approach.
- Development of parameters for crack-tip in-plane and out-of-plane constraint.

Acknowledgement:

2 TWI Ltd.
1 University of Bristol

Fig. 2 Development of parameters for crack-tip in-plane and out-of-plane constraint.

Fig. 3 (a) Half C(T) model with a/W=0.5 and T=25mm. (b) A quarter of SEN(B) model with a/W=0.5 and T=25mm.

Fig. 4 J-integral vs. Load line from C(T) model under a very low temperature.