A MODIFIED *J-Q* CONSTRAINT APPROACH TO ASSESS EFFECTIVE NOTCH FRACTURE TOUGHNESS

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Abstract

This paper uses a modified constraint-based fracture mechanics approach to estimate the effective notch fracture toughness . A modified J-Q constraint correction approach is proposed to evaluate the role of the notch tip acuity on the severity of the stress field accounting for two main characteristics, i.e. spread and maximum stress dependence of notch tip acuity. The methodology uses standard pre-cracked specimen toughness and the constraint-based approach in BS7910/R6 procedures to estimate mean values of notch fracture toughness. Experimental notch tests for S355 specimens at -140°C show good correlation with the model predictions.

1. Introduction

The value of fracture toughness (K_{mat}) used in structural integrity assessment procedures, such as BS 7910 and R6, is inherently conservative as it is commonly derived from deeply cracked specimens such as compact tension (CT) or single edge notch bend (SENB) specimens. However, many defects formed during manufacture (e.g. welding porosity) or in-service (e.g. corrosion pits) are non-sharp resulting in an increased fracture toughness, which is related to the fact that a crack needs to be initiated first before propagation.

A modified two-parameter J-Q characterisation methodology is investigated for use with non-sharp defects by comparing the constraint conditions of a SENB specimen with high constraint pre-cracks and low constraint notches. This paper describes the use of experimental testing, elastic-plastic finite element analysis and two-parameter fracture mechanics to capture the relationship between non-sharp defects and effective fracture toughness in a familiar constraint-based approach.

2. Results

Finite Element (FE) analyses of Single Edge Notch Bend (SENB) specimens containing sharp and non-sharp cracks were performed to inform the methodology. The crack tip opening stress fields ahead of the crack tip for each notch tip radius at the same applied load were extracted. These stress fields were used to define a new two-parameter approach for notches, $J - Q_\rho$. Experimental testing was used to support the FE analyses by providing a value of effective fracture for the non-sharp defects. Fracture surfaces were inspected to describe a relationship between position of peak stress at failure and position of cleavage initiation was used to define Q_ρ:

$$Q_\rho = \frac{(\sigma_{yy})_\rho - (\sigma_{yy})_{crack}}{\sigma_0}$$

where $(\sigma_{yy})_\rho$ is the stress field of the notched specimen of interest and $(\sigma_{yy})_{crack}$ is the reference stress field of the pre-cracked case. Both stresses are measured ahead of the crack tip at:

$$\frac{r'\sigma_0}{J} = 0 \qquad \text{where} \quad r' = r - n r_{\sigma_{max}}$$

where n is the linear scaler between position of peak stress and cleavage initiation. A correlation between Q_ρ and notch tip radius was defined using two specimen dependent parameters, a and b:

$$Q_{\rho}^{\{Specimen\}} = a\ ln(\rho) + b$$

These results are mapped onto a traditional $J - Q$ approach using a scaler, $\lambda = Q_{BS7190}/Q_{\rho}$, the Weibull exponent, m, and two material dependent parameters, h and l:

$$\lambda = \{m^{-0.65} \times [h \cdot \ln(\rho) + l]\}$$

This allows a constraint-based approach to be used to assess non-sharp defects in a manner that will be familiar to those that use constraint-based approaches for sharp cracks:

$$K_{mat}^{\rho} = K_{mat}[1 + \alpha(-Q_{BS7910})^{k}] \text{ when } Q \leq 0$$

A standard constraint-based approach was carried out to define α and k using specimens containing pre-cracks with different depths. The results of the approach are shown in Figure 1, showing the sharp results used to calibrate the methodology and the non-sharp results.

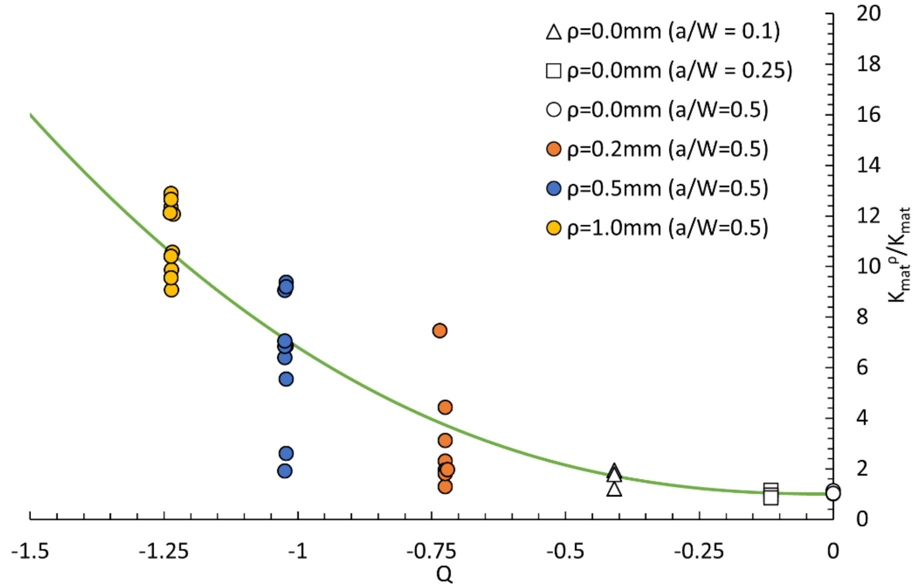

Figure 1: Constraint assessment of the non-sharp defects in the framework of a standard constraint-based fracture toughness assessment.

3. Conclusions

A two-parameter constraint-based approach to capture the effects of non-sharp defects on the level of constraint at the notch tip has been shown to conservatively capture the level of increased effective toughness. This $J - Q_{\rho}$ approach allows an assessment of notched specimens using a constraint-based approach, without requiring additional testing once material parameters are defined. Experimental validation for notched S355 specimens tested at -140ºC shows that the methodology could be promising for evaluating cleavage notch fracture toughness with no or very little experimental data.

Acknowledgements

The authors would like to acknowledge the funding provided by the UK Engineering and Physical Sciences Research Council under grant no. EP/S012362/1 and EP/R513179/1. We acknowledge the support and discussions with Prof Bob Ainsworth, Yin Jin Janin (TWI) and Dr Anthony Horn (Jacobs).