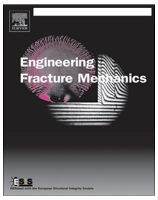
Engineering Fracture Mechanics 174 (2017) 54–63

Contents lists available at ScienceDirect

Engineering Fracture Mechanics

journal homepage: www.elsevier.com/locate/engfracmech



A transferability approach for reducing excessive conservatism in fracture assessments

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ARTICLE INFO

Article history:
Received 22 September 2016
Received in revised form 8 November 2016
Accepted 9 November 2016
Available online 11 November 2016

Keywords:
Local approach
J-Q fracture mechanics
Initiation toughness
Constraint
Notch effect

ABSTRACT

A source of uncertainty and conservatism in structural integrity assessments is the value of fracture toughness (K_{mat}) that is used. For conservative results, the value of K_{mat} is commonly derived from deeply cracked specimens, such as standard compact tension specimens, C(T). High constraint conditions near the crack tip are ensured and this corresponds to lower-bound toughness values independent of specimen size and geometry. However, the local stress fields in single edge notched tension, SE(T), specimens and pipes, for example, are known to be less severe than those at the tip of a deep sharp crack, resulting in an increased capacity to sustain load and higher toughness. Similar behaviour is expected when assessing non-sharp defects (e.g., pits, gouges, dents). The constraint loss or the notch effect produce a relaxation in the triaxial stress field in comparison to the severe stress fields present at deeply sharp cracked specimens. A methodology providing a simple procedure to evaluate the suitability of the use of a higher fracture toughness to reduce excessive conservatism is then required. This study uses a two-parameter fracture mechanics approach (*J-Q*) to quantify the level of constraint in a component (e.g. a pipe with a surface crack) and in fracture test specimens, i.e. single edge tension [SE(T)], standard compact tension [C(T)] and notched compact tension [$C(T)^{\rho}$] specimens. The ability of the structure to resist fracture is given by the fracture toughness of the test specimen with a similar *J-Q* response. Fracture toughness values for different specimens have been obtained from tearing resistance curves (*J*-R curves) constructed by means of a virtual testing framework. The proposed engineering approach is used as a platform to perform more accurate fracture assessments by the use of a ductile fracture model that informs a classical fracture mechanics approach (*J-Q*) by incorporating more fundamental understanding of the driving forces and the role of the geometry and loading conditions.

1. Introduction

In structural integrity assessments of defective components, the fracture toughness value used to determine the onset of fracture, K_{mat}, is commonly derived from deeply cracked specimens with almost square ligaments under bending, using recommended testing standards and validity criteria (e.g. ASTM E1820 [1] and ESIS-P2 [2]). These are designed to ensure high

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http://dx.doi.org/10.1016/j.engfracmech.2016.11.011
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Nomenclature

a	crack size
B	specimen thickness
E	elastic modulus
J	J-integral
$J_{0.2}^{C(T),\rho=\rho_1}$	J value at 0.2 mm crack growth for a blunt defect with notch tip radius ρ_1
K_I	mode I stress intensity factor
P	applied pressure
P_{max}	applied pressure in the FE model
Q	second parameter for characterising stress fields
ρ	notch root radius in C(T) specimens
W	specimen width
α, β, γ	material constants, see Eq. (3)
Δa	average ductile crack growth
$\Delta \varepsilon_e{}^p$	incremental equivalent plastic strain
ε_f	fracture strain
σ_0	0.2% proof stress
σ_e	von Mises effective stress
σ_m/σ_e	stress triaxiality
σ_m	hydrostatic stress
σ_1, σ_2, σ_3	principal stresses
ν	Poisson's ratio
ω, $\Delta\omega$	accumulated damage and incremental damage, respectively

Abbreviations

2-D, 3-D	two-dimensional, three-dimensional
ESIS	European structural integrity society
FE	finite element
J-R	fracture resistance in terms of J versus Δa
LLD	load-line displacement
C(T)	compact tension test specimen
SE(T)	single edge tension specimen

stress triaxiality, referred to as high constraint conditions, near the crack tip that correspond to lower-bound toughness values independent of specimen size and geometry.

In practical applications, there exist cases in which constraint conditions at a defect can be demonstrated to be lower than in deeply cracked bend specimens. For example, in the Oil and Gas (O&G) industry, during installation, regions of pipeline girth welds are predominantly loaded in tension even if the pipe is globally subjected to bending. The flaw sizes of interest are usually controlled by the weld pass height and are therefore relatively small, typically 2–6 mm in height [3]. Both loading in tension and shallow notches result in reduced crack tip constraint in the component compared to the deeply notched bend specimens.

Furthermore, there is experimental evidence for panels loaded in tension which shows that the lower constraint levels around the crack tip lead to higher resistance to fracture than would be deduced from assessments based on a fracture toughness value obtained from standard bend specimens [4]. As a result, in these cases, the material capacity to withstand load is underestimated and it would be useful to perform assessments with a fracture resistance value obtained from a test specimen with a crack tip constraint condition similar to that in the actual component [5].

Materials can exhibit an increase in fracture toughness with change of loading mode from bending to tension and/or a change from deep to shallow cracked specimen geometry for both cleavage and ductile fracture modes. Although fitness-for-service codes generally require assessments based on a lower bound fracture toughness, R6 [6] and BS 7910 [7], for example, include assessment procedures which incorporate recommendations for toughness constraint correction. These assess the constraint loss in a component based on the elastic T-stress or the normalised opening stress Q, and also require information defining the material fracture toughness sensitivity to constraint.

In this paper, attention is focussed on ductile crack propagation behaviour (microvoid growth and coalescence). A ductile fracture simulation approach which treats material ductility as a function of stress triaxiality has been implemented in previous work [8,9] to evaluate the fracture resistance curves (J-R) for different test specimens. Although these procedures are useful tools to evaluate fracture resistance for structural components, the development and calibration of the finite element