

A 3-D Framework for Fracture Assessments of Structures Using a Probabilistic Fracture Parameter

Claudio Ruggieri
University of São Paulo
São Paulo , Brazil

ABSTRACT

This study presents a probabilistic, 3-D framework to describe brittle fracture in structural components which incorporates weakest link statistics and a micromechanics model reflecting local damage of material. The Weibull stress (σ_w) emerges as a fracture parameter to define conditions leading to local material failure. This parameter is correlated with the macroscopic loading and used to describe overall fracture conditions in a cracked solid exhibiting both loss of constraint and stable crack growth prior to cleavage fracture. The paper also describes an application of the proposed framework to predict the measured geometry and ductile tearing effects on the statistical distribution of cleavage fracture toughness for an HSLA steel.

INTRODUCTION

The fracture behavior of structural components subjected to various loading and environmental conditions remains a key issue for assessments of structural integrity. The increasing demand for ensuring acceptable levels of structural safety has spurred a flurry of predictive methodologies aimed at quantifying the impact of defects in load-bearing materials such as, for example, cracks in critical weldments of offshore structures. Such methodologies play a key role in repair decisions and life-extension programs for in-service structures, including marine facilities and ocean structures. For ferritic materials at temperatures in the ductile-to-brittle transition (DBT) region, fracture by transgranular cleavage along well defined, low index crystallographic planes is the dominant operative micromechanism. This failure mode potentially limits the load bearing capacity of the structure as local crack-tip instability may trigger catastrophic failure at low applied stresses with little plastic deformation.

Conventional fracture assessments of large engineering structures using laboratory specimen data most often employ a

one-parameter characterization of loading and toughness such as the Mode I stress intensity factor, K_I , the J -integral or the crack tip opening displacement (CTOD) (Hutchinson, 1983). The more recent two-parameter approaches (T -stress and J - Q methodologies) retain contact with traditional fracture mechanics and provide a concise framework to represent measured toughness values in terms of a J - T or J - Q locus (Parks, 1992). However, such methods are conservative (i.e., the failure of a cracked component at a given load is over-predicted) and do not provide a means to *predict* the effects of constraint variations and prior ductile tearing on toughness. Further, cleavage fracture is a highly localized, inherently random phenomenon which exhibits strong sensitivity to material characteristics at the microlevel. In particular, the random inhomogeneity in local features of the material causes large scatter in experimentally measured values of fracture toughness (K_{Ic} , J_c , CTOD). Consequently, realistic methodologies for fracture assessments of structural components must adopt a probabilistic, rather than a deterministic, treatment of fracture.

As a step in this direction, we present a probabilistic, 3-D framework to describe brittle fracture in structural components which incorporates weakest link statistics and a micromechanics model reflecting local damage of material. The objectives in developing probabilistic models to describe unstable crack propagation are essentially two fold. First, for a structure containing cracks of different sizes and subjected to complex loading histories, we seek to determine probability distributions for the (local) fracture stress which couple remote loading (as defined conveniently by J or CTOD) with the operative fracture mechanism at the microlevel. In the context of probabilistic models, a fracture parameter associated with the probability distribution then describes macroscopic fracture behavior for a wide range of loading conditions and crack configurations. The Weibull stress (σ_w) (Beremin, 1983) emerges as a fracture parameter to define conditions leading to (local) material failure. This parameter is correlated with the macroscopic loading and used to describe