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Assessment of constraint independence and temperature dependence of critical fracture energy, G_{fr}

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Abstract

Characterisation of ductile fracture is a major problem, especially in the nuclear industry where the material behaviour needs to be characterized over a wide range of temperature considering the embrittlement of the material due to irradiation.. Use of the J-Δa curve for stable crack growth is useful, but transfer of crack growth curve from specimen to component is difficult due to dependence on constraint (geometry, a/W).A new fracture parameter critical fracture energy, G_{fr}, based on segregation of fracture energy from total energy is explored to simulate ductile crack growth during ductile tearing test by Marie and Chapuliot. The present work aims in estimating G_{fr} for the material 20MnMoNi55 steel for different initial a/W ratio, different crack growth and the independence of G_{fr} on these parameters is verified. As ductile material starts behaving in a brittle manner at low temperature so it is expected that the estimated G_{fr} will decrease with the decrease in temperature. In this work G_{fr} is also measured at different low temperatures (20^0C to -80°C) and is observed to be decreasing with temperature.

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*Keywords:*Critical Fracture Energy G_{fr};Modified J-integral J_{m-pl};Ductile Crack Growth

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1. Introduction

In recent years there has been a growing interest in studying the behaviour of cracked components. The failure sequence for a ductile specimen or a structure containing a pre-existing crack is fracture initiation, stable crack growth under prescribed loading conditions and final instability. Fracture initiation has been well characterized in terms of critical value J_{IC} of the J-integral, provided certain geometrical considerations are satisfied. However, characterisation of ductile fracture is a major problem, especially in the nuclear industry where the material behaviour needs to be characterized over a wide range of temperature considering the embrittlement of the material due to irradiation.
Several candidate fracture parameters have been used to quantify crack growth in the elastic-plastic regime which include stress intensity factor, integral parameters such as J-integral, energy release rates such as G^{Δ} and geometric parameters such as crack tip opening displacement. Each of the fracture parameter fails to meet one or more of the necessary requirements. There are not many solutions to simulate crack growth during ductile test. Use of the J-Δa curve for stable crack growth is popular, although it is accepted that the J-Δa curve may depend on the geometry of the specimen or the component and hence transfer of laboratory test data to the actual component is not straightforward. Serious attempts have been made to modify J-a curve so that a unique curve relating J and crack growth can be used to describe stable crack growth and equally applicable for both specimen as well as the component. To resolve this problem, new approaches were developed which can be classified into two:

1. The two-parameter global approach adds to the J-integral a second parameter which characterizes the geometry and loading conditions. The most well known models are J-T model proposed by C Bertegon and J.W. Hancock (1991) and J-Q model proposed by N. P. O'Dowd and C. F. Shih (1991). However there are very few works using these approaches without any real success.
2. Another approach are the local approaches proposed by A.L. Gurson (1977), V. Tvergaard et al. (1984), Rousselier G. (1987) where the crack growth is described by modelling the local fracture by micromechanical models which aims to model the damage which occurs in three different stages: nucleation, growth and coalescence of voids. Disadvantages of these local approaches by A.L. Gurson (1977), V. Tvergaard et al. (1984), Rousselier G. (1987) are:
   - Numerically heavy in case of complex structures.
   - Need for estimating several material parameters which are difficult to estimate.
   - Mesh size dependence.

Marie and Chapuliot (1998) used the concept introduced by Turner (1990) i.e. the energy dissipation rate to simulate stable crack growth for a ductile specimen. Here a crack growth criterion is propounded by associating energy dissipation rate with an energy release rate G_{fr}, calculated locally near the crack tip and by defining the energy required for a finite crack extension λ. They also proposed several methods to calculate G_{fr} which has been discussed in details in the next section.

Nomenclature

G_{fr}	Critical Fracture Energy	J_{M-pl}	Modified J-integral
G_c	Critical Energy Release Rate	J_{pl}	Plastic J-integral
du_t	Total Energy Balance supplied to crack system	$\gamma(a)$	Parameter which is a function of crack length and hardening exponent.
dU_e	Total Elastic Energy	B	Thickness of the specimen
dU_d	Total Dissipated Energy	b	Un-cracked Ligament Length
dU_{gpl}	Total Global Plastic Energy	da	Change in crack length
dU_{fr}	Total Change in Fracture Energy	a_f, a_0	Final crack length, Initial Crack Length