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Time-dependent cohesive zone modelling for discrete fracture simulation

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ABSTRACT

The cohesive crack tip model became very popular in fracture and failure mechanics, starting with the original publications of (Dugdale, 1960) [1] and (Barenblatt, 1962) [2] and first practical applications in the early 1980s. A compact representation of the fracture mechanical basis, kinematic and constitutive issues as well as some special characteristics of the related finite element formulation are given in the first part of this contribution. The main part is dedicated to the presentation and discussion of recent developments of cohesive finite element methods for time-dependent fracture. On the basis of a rheological model assumption, a novel viscoelastic extension for cohesive traction separation laws is presented and the resultant characteristic behaviour is depicted and compared for different loading conditions. Adopting an industrial application of a peel foil specimen, the time-dependent characteristics as well as some aspects of parameter identification and application of the material model are shown.

1. Introduction

The prevailing part of cohesive crack tip research and application is related to finite element (FE) implementations and corresponding cohesive elements. Especially in this field, a huge amount of work has been done in the last two decades and the application range of the finite element method was extended significantly due to the capability to represent a discrete discontinuity within the displacement field. At first, a compact view on the most relevant developments of the last few years in the field of cohesive zone related research is given. Starting with the classification of the cohesive crack tip approach in the field of fracture mechanics, the basic kinematic and constitutive formulations are presented in a consistent framework. Furthermore, some unique characteristics of this special type of finite elements are pointed out. The main part is related to cohesive material formulations which are able to consider rate-dependent separation effects during the crack opening process. Subsequent to the discussion of some relevant proposals from the literature, a formulation based on a rheological model assumption is derived, presented in detail and demonstrated by means of suitable numerical examples. The new application range is demonstrated by the numerical investigation of a peel foil system.

1.1. Fracture mechanical aspects

The origin of fracture mechanics as an engineering discipline is strongly related to the assumption of the energy balance

$$\frac{\mathrm{d}W}{\mathrm{d}A}-\frac{\mathrm{d}U}{\mathrm{d}A}=\frac{\mathrm{d}\Pi}{\mathrm{d}A}=\frac{\mathrm{d}\Gamma}{\mathrm{d}A} \tag{1}$$

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Nomenclature

Operators

$[\![\bullet]\!]$	jump operator
$\langle\bullet\rangle$	McCauly bracket
$\dot{\bullet}$	derivation with respect to time
$\int\bullet$	integration

Indices

0	initial value
c	critical value
n, N	normal components
t, T	tangential components

Fracture mechanics

E	Young's modulus
σ_Y	yield stress
f_t	tensile strength
γ	surface energy
G	energy release rate
G_c	fracture toughness

Cohesive material

Γ	cohesive fracture energy
Γ_0	work of separation
T_0	maximum traction value, strength of the cohesive surface
$\mathbf{T}$	traction vector
T_N, T_T	normal and tangential traction components
$\boldsymbol{\delta}$	separation vector, displacement jump vector
δ_N, δ_T	normal and tangential separation components
δ_0	maximum separation value, relative displacement of traction free surfaces
δ_{N0}, δ_{T0}	normal and tangential components of δ_0
D	damage parameter, interaction criterion
μ	coefficient of friction, rheological model contribution

as a critical condition for fracture. This equation relates potential energy changes $\mathrm{d}\Pi$, consisting of external work W and internal strain energy U contributions, and the fracture energy Γ at incremental crack growth $\mathrm{d}A$. The strain energy release rate

$$G = \frac{\mathrm{d}W}{\mathrm{d}A} - \frac{\mathrm{d}U}{\mathrm{d}A} \tag{2}$$

and the relation between crack length and fracture energy changes

$$\mathrm{d}\Gamma = \dot{\Gamma}\mathrm{d}t = 2\gamma\mathrm{d}A \tag{3}$$

enables the reformulation of Eq. (1) in a general manner as

$$G = 2\gamma = G_c \tag{4}$$

which is valid for an elastic-brittle material with quasi-static and stable crack propagation. Furthermore, a process zone around the crack tip with an elliptic shape (see Fig. 1a) and small dimensions compared to all other length scales is assumed and incorporates the separation process as well as all inelastic deformations. Accordingly, the value of Γ consists of both con-

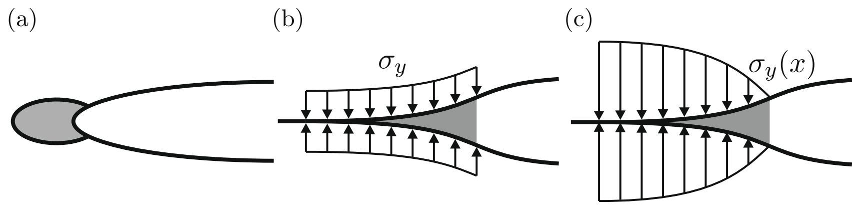

Fig. 1. Crack tip models of (a) Griffith, (b) Dugdale and (c) Barenblatt.