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Guidelines for Applying Cohesive Models to the Damage Behaviour of Engineering Materials and Structures

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Summary

This document describes the guidelines for the application of cohesive models to the evolution of damage in materials and structures. The material is characterised by a specific constitutive law, the cohesive law, which is assigned to cohesive elements. These cohesive elements are embedded in a finite element mesh of the structure under consideration.

The cohesive law relates the tractions acting on the cohesive element surface to the material separation and is therefore called traction-separation law (TSL). It can be described by a function, which includes three material parameters:

- The cohesive strength, T_0,
- The cohesive energy, Γ_0, and
- The critical separation, δ_0,

which are determined by hybrid experimental/numerical procedures. In addition, the shape of the function must be determined or predefined for a complete description of a cohesive law. If, however, for a given class of materials the shape of the cohesive law is fixed, then only two parameters are needed. In this procedure, the cohesive stress and the cohesive energy are considered the relevant parameters.

The methods described in this procedure can be used for the determination of damage in materials and structures with and without pre-existing flaws, and hence for structural assessment. They are based on experience with metallic materials gained at the Helmholtz-Zentrum Geesthacht (formerly GKSS) as well as taken from the literature. The first part of the suggested procedure describes the material characterisation. In the following section areas of application are compiled. A particularly interesting area of application is the prediction of slow, stable crack extension in thin-walled lightweight structures. Open issues are also briefly described.

In an appendix validation by means of test pieces and application to some structural configurations are given.

Definitions

Traction–Separation Law

A set of equations (also known as cohesive law) describing the relationship between a stress and a separation within the cohesive elements, from zero separation up to loss of coherence.

Ductile Tearing

Crack extension due to micro-void formation and coalescence.

Cohesive Strength

Maximum stress of the traction–separation law.

Cohesive Energy

Area under the curve describing the traction–separation law

Damage

Irreversible process that causes material degradation and finally causes failure. The kind of damage and thus the affected material volume depends on the micromechanisms of damage.

Separation

Phenomenological description of material damage and failure by assuming that two initially connected material points separate by some damage process.

Finite Element Method (FEM)

Numerical method based on the principle of virtual work to effectively calculate the material behaviour by dividing a structure into elements with simple displacement formulations.

Cohesive Element

The cohesive element is a special numerical formulation within the framework of finite elements which is able to model the material separation by a cohesive law.

Global Mode I Fracture
Global loading which produces a typical mode I stress field.

Flat Fracture
Fracture surface which evolves normal to the applied loading direction under →*Global Mode I* Fracture conditions.

Slant Fracture
Fracture surface which evolves frequently for thin-walled panels. It turns to 45° (out-of-plane) with respect to the global crack propagation direction.

Normal Separation
Expression used only in the context of cohesive elements. Normal separation is the opening mode of the cohesive elements normal to its interface orientation

Tangential Separation
Like → *Normal separation* only used in the context of cohesive elements. Opening mode of the cohesive elements in the plane of the interface element.

Stable Crack Extension
Crack extension, which, under displacement control, stops when the applied displacement is held constant.

Fracture Resistance
The resistance a material exhibits to stable or unstable crack extension, expressed in terms of K, δ_5, J or CTOA.

Nomenclature

Dimensions

- a Crack length
- a_0 Initial crack length prior to ductile crack extension
- t Specimen thickness
- W Specimen width

Tensile Properties

- E Young's modulus
- ν Poisson's ratio
- $R_{p0.2}$ Yield strength equivalent to 0.2 % proof stress
- R_m Tensile strength
- σ_Y Yield strength, general

Forces, Stresses and Displacements

- F Applied force
- h Stress triaxiality, calculated by σ_m/σ_{eff}
- v_{LL} Load-line displacement
- σ Normal stress
- σ_{eff} Effective stress
- σ_m Mean stress, also called hydrostatic stress, $\sigma_m = \sigma_{ii}/3$

Fracture Parameters and Related Quantities

- Δa Crack extension
- J Fracture resistance in terms of the experimental equivalent of the J-integral
- J_i Value of J at initiation of ductile tearing
- Ψ Crack tip opening angle

δ_5 Crack opening displacement measured at the surface of a specimen or structural component at either side of the original crack tip over an initial gauge length of 5 mm

Cohesive Parameters

T Cohesive stress
T_0 Cohesive strength
Γ_0 Cohesive energy
δ Separation
δ_0 Critical separation
δ_n Separation normal to the fracture surface
δ_t Separation tangential to the fracture surface

The SI Units to be used in this Procedure are:

F Force, kN
σ, T Stress, MPa
δ_5 Displacement, mm
Δa Crack extension, mm
J Experimental equivalent of *J*-integral, MPa m

Acronyms

CMOD Crack mouth opening displacement
CTOA Crack tip opening angle
CTOD Crack tip opening displacement
TSL Traction—separation law
FEM Finite Element Method