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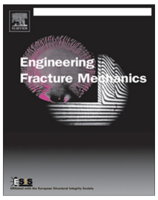

Effects of the cohesive law on ductile crack propagation simulation by using cohesive zone models

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ABSTRACT

The cohesive zone model has been applied in different computational fracture mechanical investigations. However, effects of the cohesive law on crack simulation results have not been systematically and quantitatively studied. To quantify the influence of the cohesive law, a special cohesive element has been developed and implemented into the commercial FEM code ABAQUS. The detailed computational investigation of compact tension (CT) specimens confirms that the load vs. load line displacement curve hardly depends on the initial cohesive stiffness of the cohesive zone, but the fracture parameters, such as δ_5, may deviate up to 5%. A significant difference is observed in prediction of crack propagation, which exceeds 35% for a given load line displacement in CT specimens. To diminish artificial influence of the cohesive zone model, one has to increase the specific cohesive stiffness. The *J*-integral as the critical energy release rate generally differs from the cohesive energy. The elastic unloading and plastic reloading around the cohesive zone affect the fracture energy amount. The difference between the cohesive energy and the critical energy release rate depends on the cohesive law as well as the ductility of the material, vanishes only in an elastic specimen and exceeds 40% for ductile materials. The discrepancy between *J* and the cohesive energy grows and is stagnated for the cohesive strength larger by three times the initial yield stress. To obtain realistic computational results by using cohesive zone models, one has to build the cohesive law with proper parameters.

1. Introduction

Material failure is often accompanied by elastic unloading and plastic reloading round the crack tip. This problem becomes especially significant for elastic–plastic crack propagation under low cycle fatigue conditions, where the Paris' law cannot be applied due to large scale of non-proportional inelastic deformations. Recently, the cohesive zone model is popular in computational fracture mechanics' community due to its simple formulation, easy implementation in FEM codes and flexible applications in crack analysis. One of key advantages of the cohesive zone model is in separating the material deformation from material failure in computations [1]. That is, material deformation in a cracked specimen is described by the continuum plasticity, whereas material damage is predicted by the cohesive zone model. The fracture process zone is simplified into a strip ahead of the crack tip. Obviously, the accuracy of the cohesive zone modeling is influenced by constitutive description of the cohesive zone. Quantification of effects of different cohesive zone models is still an open issue.

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Nomenclature

Δa	crack growth
Δa_0	crack growth predicted by the rigid cohesive model ($\delta_1 = 0$)
E	Young's modulus of the bulk material
J_i	J-integral at crack initiation. For path-dependent cases, J_i will be evaluated in the far field.
n	strain hardening exponent in the Ramberg–Osgood model
$\mathbf{T}$	traction vector in the cohesive zone
t_i	traction vector, $t_i = \sigma_{ij} n_j$
$T_{\max}$	the maximum traction in the cohesive law
u_i	displacement vector
V_{LL}	load line displacement
W	strain energy density
α	plastic offset in the Ramberg–Osgood model
$\boldsymbol{\delta}$	separation vector in the cohesive zone
δ_0	the separation when the traction vanishes.
δ_1	the separation when the traction reaches the maximum.
δ_2	the separation when the traction decreases, i.e. the cohesive begins to damage.
δ_5	the CTOD defined by Schwalbe
δ_{50}	the CTOD defined by Schwalbe for the crack simulation with the rigid cohesive zone model ($\delta_1 = 0$)
ε	strain
Γ	cohesive energy for creating a unit crack surface
Ψ	the cohesive stiffness, $\Psi = T_{\max}\zeta/\delta_1$
ν	Poisson ratio
σ	Cauchy stress
σ_0	yield stress of the bulk material
ζ	characteristic length of the cohesive zone

Material behavior in the cohesive zone is described by the cohesive law, which should represent the collective behavior of material damage. The cohesive law is responsible for material degradation under different loading configuration and defines the continuous traction–separation correlation in the cohesive zone. In general cases both variables are vectors, so the cohesive law is defined in a vector equation. For a mode I crack, however, only the normal traction vs. normal separation plays a role in material failure, that is, the cohesive law is expressed in a traction–separation function, $T(\delta)$, as shown in Fig. 1.

At very low loading level of a cracked specimen, the fracture process zone is vanishingly small, the material around the crack is not damaged and the cohesive zone should not exist. It follows that the cohesive zone initiates only if the traction ahead of the crack tip exceeds a critical value, i.e. the threshold value of the traction. In this case, the initial stiffness of the

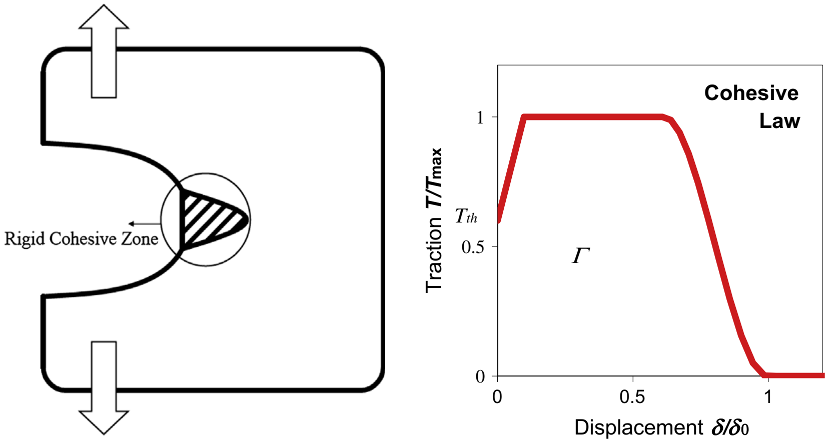

Fig. 1. The cohesive zone ahead of the crack tip described by a cohesive law with threshold, T_{th}. The cohesive energy Γ denotes the area under the cohesive curve.