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A comparison of cohesive zone modeling and classical fracture mechanics based on near tip stress field

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Abstract

A mode III crack with a cohesive zone in a power-law hardening material is studied under small scale yielding conditions. The cohesive law follows a softening path with the peak traction at the start of separation process. The stress and strain fields in the plastic zone, and the cohesive traction and separation displacement in the cohesive zone are obtained. The results show that for a modest hardening material (with a hardening exponent $N = 0.3$), the stress distribution in a large portion of the plastic zone is significantly altered with the introduction of the cohesive zone if the peak cohesive traction is less than two times yield stress, which implies the disparity in terms of the fracture prediction between the classical approach of elastic–plastic fracture mechanics and the cohesive zone approach. The stress distributions with and without the cohesive zone converge when the peak cohesive traction becomes infinitely large. A qualitative study on the equivalency between the cohesive zone approach and the classical linear elastic fracture mechanics indicates that smaller cracks require a higher peak cohesive traction than that for longer cracks if similar fracture initiations are to be predicted by the two approaches.

Keywords: Cohesive zone; Cohesive traction; Fracture mechanics; Elastic–plastic deformation; Antiplane shear

1. Introduction

In recent years, the cohesive zone modeling approach has emerged as a popular tool for investigating fracture processes in materials and structures (see, for example, Needleman, 1987; Tvergaard and Hutchinson, 1992; Xu and Needleman, 1994; Ortiz and Pandolfi, 1999; Roy and Dodds, 2001; Elices et al., 2002;

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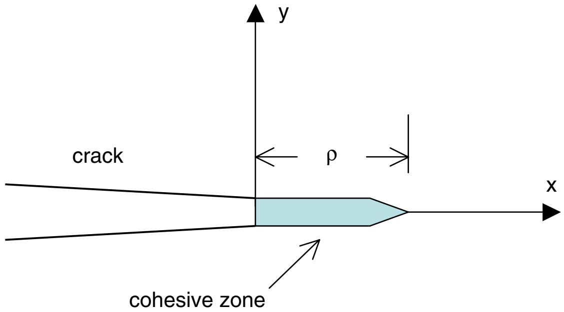

Fig. 1. A cohesive zone ahead of a crack.

de Borst, 2003; Scheider and Brocks, 2003; Jin and Sun, 2005a). In a cohesive zone model, a narrow-band of vanishing thickness termed the cohesive zone is assumed to exist ahead of a crack tip (see Fig. 1) to represent the fracture process zone. The upper and lower surfaces of the narrow-band are termed as the cohesive surfaces and are acted by the so-called cohesive traction which follows a cohesive constitutive law that relates the cohesive traction to the separation displacement of the cohesive surfaces. Crack growth occurs when the separation at the tail of the cohesive zone (physical crack tip) reaches a critical value at which the cohesive traction vanishes. Clearly, the cohesive zone modeling approach does not involve crack tip stress singularities in classical fracture mechanics, and material failure is controlled by quantities such as displacements and stresses, which are consistent with the usual strength of materials theory.

Barenblatt (1962) proposed a cohesive fracture concept aiming to eliminate the crack tip stress singularity in the classical linear elastic fracture mechanics (LEFM). The strip yield zone model of Dugdale (1960), which was proposed for estimating the crack tip plastic zone size, has also been regarded as a cohesive zone type model with the strip yield zone treated as a cohesive zone. Mathematically, a cohesive zone model is described by a cohesive law or the relationship between the cohesive traction σ and the opening displacement (separation) δ of the cohesive surfaces as follows:

$$\sigma = \sigma_c f(\delta/\delta_c), \tag{1}$$

where σ_c is the peak cohesive traction, δ_c a characteristic opening, and f a dimensionless function describing the 'shape' of the cohesive traction–separation curve (cohesive curve). A fundamental parameter of the cohesive zone model (1) is the cohesive energy density, or the work of separation per unit area of cohesive surface, defined by

$$\Gamma_c = \int_0^\infty \sigma(\delta)\,d\delta. \tag{2}$$

Although the cohesive zone modeling approach has been used by many authors for more than a decade, the physical reality of the cohesive zone is still an issue for debate. Since it has no thickness but has a limiting stress level that affects the stress field in the region surrounding it, the cohesive zone model cannot be identical to the classical continuum fracture mechanics. In recent years, there have been attempts to interpret some of the distinct narrow deformation bands (e.g., necking in ductile thin sheets and crazing in some polymers) that are generated ahead of the crack tip as a cohesive zone. For these physical "cohesive zones", the cohesive characteristics (σ_c, δ_c, Γ_c and f in (1) and (2)) may be determined directly by analyzing the stress and deformation states in the band. For example, Jin and Sun (2005b) developed a cohesive zone model for ductile thin sheet materials by treating the crack front necking zone as the cohesive zone. If such a distinct narrow deformation band is not present, the cohesive zone can only be regarded a hypothesis or an approximate representation of the crack tip process zone and, consequently, the cohesive zone param-