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PREDICTION OF DAMAGE EVOLUTION IN BONDED MATERIAL USING COHESIVE ZONE MODEL

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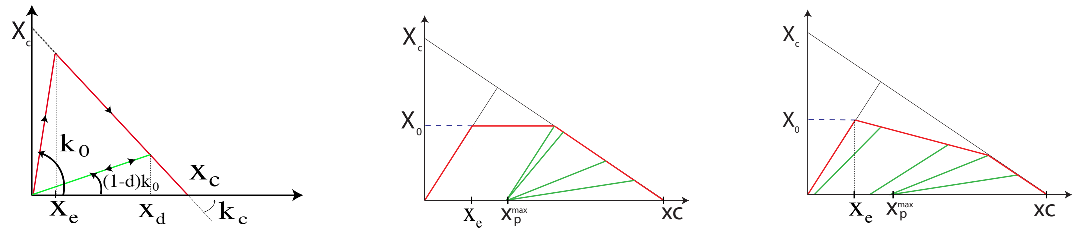
Asymptotic numerical methods (ANM) are useful for monitoring highly non-linear response curves, such as those given by plasticity, damage and crack propagation. ANM are based on the computation of a Taylor series expansion per step [1]. Unfortunately they cannot be directly used for nonsmooth behaviours such as plasticity or damage because the Taylor series exists only if the governing equations are defined by regular functions. Nevertheless, non-smooth constitutive equations can be regularised as proposed in [2, 3].

In this work, a relevant ANM computational procedure is presented to predict onset and crack growth in the Continuum Damage Mechanics (CDM) framework using cohesive zone model and irreversible thermodynamics concepts. The existence of irreversible processes induced by plasticity and damage evolution legitimates the introduction of intrinsic dissipation. For the sake of simplicity, we limit our analysis to 1-D damageable interfaces. The interface models, considered hereafter, relate normal load to normal displacement discontinuity. This modelling approach is often used to describe the initiation of composite delamination [4] or crack propagation. We will progressively consider: the elastic-damageable interface law Fig.1(a), the sequential perfect-plastic-damageable interface laws Fig.1(b) and the coupled plastic-damageable law Fig.1(c). In the generalized standard materials (GSM) framework, free energies are formulated respectively for the elastic-damageable model, denoted $\Psi_1(x, x_d)$, and for the plastic-damageable models, denoted $\Psi_2(x, x_d, x_p)$:

$$\Psi_1(x, x_d) = \frac{1}{2}\left(\frac{\delta_c}{x_d} - 1\right) k_c x^2 \quad ; \quad \Psi_2(x, x_d, x_p) = \frac{1}{2}\left(\frac{\delta_c - x_p^{max}}{x_d - x_p^{max}} - 1\right) k_c (x - x_p)^2 \qquad (1)$$

where x is the normal elongation discontinuity, x_p the normal plastic elongation discontinuity, x_p^{max} the maximal plastic elongation discontinuity and x_d the normal damage displacement discontinuity. These quantities are developed in Taylor series to use ANM. The state variable x_d can be easily related to the damage variable d classically used to



(a) Elastic-Damageable model

(b) Perfect-Plastic-Damageable model

(c) Coupled-Plastic-Damageable model

Figure 1: Cohesive zone models

assess the loss of stiffness Fig.1(a). Various yield functions only depending on the thermodynamics forces X_{x_d}, X_{x_p} are used to introduce the coupling between plasticity and damage:

$$f_0(X_x, X_{x_d}, X_{x_p}) \;=\; sup(\frac{X_{x_d}}{X_c}, \frac{X_{x_p}}{X_0}) - 1 \quad ; \quad f_1\left(X_x, X_{x_p}, X_{x_d}\right) \;=\; \mid \frac{X_{x_p}}{X_0^1} \mid + \mid \frac{X_{x_d}}{X_c^1} \mid -1 \tag{2}$$

This thermodynamics forces can be related to conjugated variables by: $X_{x_k} = -\frac{\partial \Psi_2}{\partial x_k}$, for $k \in d, p$, the intrinsic dissipation being defined by $D = F_{coh}\dot{x} - Y_x\dot{x} - Y_{x_d}\dot{x}_d - Y_{x_p}\dot{x}_p$. The normal cohesive load is given by $F_{coh} = \frac{\partial \Psi_2}{\partial x}$.

The use of $f_0(X_x, X_{x_d}, X_{x_p})$ as yield function associated with $\Psi_2(x, x_d, x_p)$ first induces a plastic phase and followed by a damage phase Fig.1(b). The use of $f_1(X_x, X_{x_d}, X_{x_p})$ associated with the same free energy induces first a phase where damage and plasticity simultaneously developed and follow by a purely damage phase leading to rupture Fig.1(c). Interface Behaviour depends not only on free energy form but naturally also of the choice of the yield function describing the nature and coupling of the irreversibility. Other yield functions can naturally be considered. Finally, the progressive degradation in term of plasticity and damage of a cohesive surface between two cantilever beams will be considered to highlight interest of ANM approaches for simulating the ruin of engineering structures.

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