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► **To cite this version:**

Paul Emile Bernard, Nicolas Moes, Claude Stolz, Nicolas Chevaugnon. A thick level set approach to model evolving damage and transition to fracture. ECCM 2010 - The 4th European Conference on Computational Mechanics, ECCOMAS; AFM/CSMA, May 2010, Paris, France. hal-01154912

**HAL Id: hal-01154912**

**<https://hal.science/hal-01154912v1>**

Submitted on 25 Mar 2024

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# A thick level set approach to model evolving damage and transition to fracture

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Local damage models are known to suffer from spurious localization and present therefore a high sensitivity to the mesh. Several damage models were proposed in the literature to avoid these issues [1], as for instance non-local damage models [2, 3] or higher order gradients models [4, 5]. We proposed a new approach for damage growth modeling in solids [6], using level set functions to represent the damaged zones. The *damage front* is then located on the iso-zero of the level set. Its propagation can be described in terms of the energy along the front while its curvature is used to introduce a characteristic length in the model.

We present here an improved version of the damage front model, in which a scalar damage variable  $d(\phi)$  is expressed as a continuous function of a level set  $\phi$ . The damage front becomes a *damage band* comprised between  $d = 0$  and  $d = 1$  and a transition zone from full damage to the sane material naturely appears, with a characteristic thickness  $l_c$  equal to the averaged damage gradient  $d'$ . The configurational force driving the damage front propagation is averaged over the transition zone, providing a non-local well-posed model.

This new approach presents many advantaging features: the initiation and the merge of cracks does not require any special treatment, the scenario of the damage variable getting to 1 is included and the specific numerical treatment for non-locality is limited to a band around the defects.

An explicit propagation algorithm is used consisting in an optimization of the front velocity at each time step. A power law type damage evolution law with a threshold is assumed,

$$\dot{d} = k \langle Y - Y_c \rangle_+^n$$

where

$$Y = \frac{\partial \psi(d)}{\partial \dot{d}}$$

is the local energy release rate and  $\psi(d)$  a dissipation potential [7]. A dual potential  $\psi^*(Y)$  is derived from  $\psi$  using the Legendre-Fenchel transform, providing the following inequality:

$$\psi^*(Y) + \psi(d) - Yd \geq 0 \quad .$$

In the framewotk of a non-local model, we seek the field  $\dot{d}$  minimizing this inequality. Since  $d$  is a function of the level set,  $\dot{d} = d'(\phi)v_n$  and the problem is equivalent to find the front normal velocity  $v_n$  minimizing the following:

$$\min_{v_n} \int_{\Omega_b} \psi(d'(\phi)v_n) - Yd'(\phi)v_n d\Omega \quad ,$$

with  $\Omega_b$  the damage band  $0 \leq \phi \leq l_c$  around defects. This front velocity is forced positive through the use of Lagrange multipliers.

The advantages of the new approach are illustrated in some examples as the three points bending test case, the brasilian test case and the merging and branching of damage zones. The numerical results are in good agreement with the experimental measurements and are consistent with fracture mechanics computations using the extended finite element method.

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