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Concurrent development of local and non-local damage with the Thick Level Set approach: implementation aspects and application to quasi-brittle failure

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1. Introduction

Quasi-brittle failure is commonly characterized, at the macroscopic scale, by a strain localization followed by the emergence of a crack. Strain localization appears in a privileged region called the fracture process zone. At a lower scale, strain localization results from a microcracking process and macrocracks are the consequence of microcracks growth and coalescence. In the present paper a quasi-brittle failure model is developed at the macroscopic scale.

Modeling quasi-brittle failure can be achieved in several different ways. A first one consists in extending the linear elastic fracture mechanics by adding cohesive zones on crack tips in which cohesive tractions gradually decay as the crack faces separate [1, 2, 3]. Another way consists in using continuum damage mechanics [4, 5, 6]. Within this theory, material behavior softens through the use of a damage internal variable which models microcracking effects. Unfortunately, local rate-independent damage models are known to allow solutions which are not acceptable (crack creation without dissipation [7]). This theoretical issue affects the numerical simulations by spurious mesh dependencies.

Several models have been proposed in the literature to make sure that solutions reach a proper level of dissipation by avoiding damage to localize in an infinitely narrow band. They can be classified into different categories as integral based [8, 9], differential (gradient dependent) based or rate based [10, 11]. Regarding the gradient based category, one may even distinguish between the introduction of higher order kinematics [12] or damage gradient in the description of the energy [13]. The latter category involves more recent approaches as the variational approach to fracture [14] as well as the phase-field approach [15]. A recent paper [16] details the similarities and differences between the initial gradient damage approach and the phase-field approach.

Note that, as it should be, the above models do not necessarily ensure uniqueness of the solution, bifurcations are still possible and must ideally be taken into account in the simulation. Even though the above models avoid spurious localization, the transition to a crack (displacement discontinuity) is not directly addressed by the existing models. The crack placement is an extra step. Several papers are devoted to crack placement within damaged zone, see for instance [17, 18, 19].

The TLS model follows a different line of thought. It merges the capabilities of the strong discontinuity approach and of continuum based damage model. On one hand, damage is used to predict crack initiation and to handle complex crack patterns (topological changes such as crack birth coalescence and branching). On the other hand, the discontinuity capability is