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Damage growth modeling using the Thick Level Set (TLS) approach

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ABSTRACT

The aim of our work is to build a model to predict the full scenario of degradation of solids under mechanical loading. Such a model involves the interaction of complex processes and obviously requires at least two main ingredients: fracture and damage mechanics. On one side, although the basis of fracture mechanics can be considered as well-known, processes as cracks initiation, merging or branching are still difficult to both model physically and represent numerically. Classical numerical representations of cracks, based on the eXtended finite element method [1] using level set functions quickly becomes a tedious task as the number of cracks grows and crack merging is hard to handle. It is now commonly admitted that fracture mechanics alone is insufficient to model the entire degradation process. Prediction of phenomena as crack initiation requires damage mechanics. However, the link between damage and crack is not obvious from both the physical and numerical point of view.

The alternative is damage mechanics. It is well known that local damage models may experience spurious localization and mesh dependencies when considering localization phenomena. Several models have been developed to avoid these issues. All of these models introduce somehow, explicitly or not, a characteristic length (l_c) to obtain non-locality. Classical non-local integral damage models are based on an averaging operator [3], to obtain a non-local driving force, responsible for the damage growth. Such approaches may lead to relatively high computational cost since, averaging the local driving forces is done everywhere. Moreover, the average itself requires to take topological interactions into account, especially when averaging close to notches, boundaries or cracks. Solving these problematic topological interactions is still difficult. The high-order gradient models is an alternative non-local model. The additional cost of such methods cannot be neglected since new variables and corresponding relationship have been added to the problem over the whole domain, not to mention the need to find appropriate boundary conditions for the unknown gradients. Comparison between these two families of methods can be found in Perlings et al [4]. A third kind of method avoiding spurious localization is the phase-field approach [5]. A phase field varying from 0 to 1 is introduced to characterize the material degradation, providing a transition zone between sane and destroyed material. A new phase equation presenting a laplacien operator is added to the mechanical equations, providing an additional characteristic length to the problem. This additional variational formulation is again solved over the whole domain.

In this framework, the TLS model [2] has been developed to obtain an efficient and thermodynamically consistent non-local damage model, to provide answers to the fracture mechanics questions of crack initiation, branching and merging, and offer a natural transition between damage and fracture. The main idea of the TLS approach is to locate a damaged zone, possibly multiply connected, using a single level set function. This easily solves the numerical questions of merging or branching. The iso-zero of the level set ϕ is called the damage front and corresponds to the transition between the sane and

the damaged material. In the TLS model, damage is considered as a given (increasing) function of the level set, $d = d(\phi)$. The damage raises from 0 to 1 as ϕ goes from 0 to l_c . Therefore, the minimum distance between a point where $d = 0$ and a point where $d = 1$ is l_c , preventing spurious localization. This approach appears to be very promising in view of the following points : The non-local treatment is local: it only requires a special treatment in the transition zone, where $0 \leq d \leq 1$, leading to lower computational costs. The non-locality only appears where and when needed, without additional variable or equation to solve over the whole domain. The transition from damage to crack is automatic. The non-local TLS model tends to the local model as the transition zone tends to zero: the damage initiation is simple and well-posed. Compared to standard non-local integral models, the characteristic length of the non-local operator is not fixed, but automatically varies from 0 to l_c as the damage grows, avoiding topological issues around cracks.

The objective of the present communication is to present and discuss the TLS method and provide examples of application to the prediction of crack branching, merging or initiation (see figure 1).

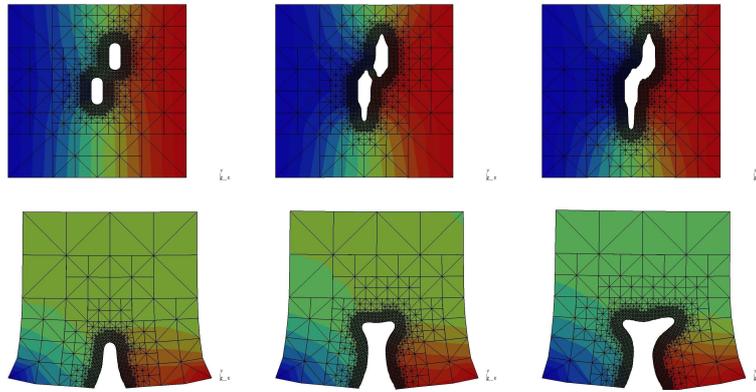


Figure 1: Top : Merging of two damaged zone, Bottom: Branching of a crack encountering a stiffer material.

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