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# Numerical modelling of growth and propagation of interfaces by means of the embedded discontinuities approach.

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**ABSTRACT**

Object of the contribution is the numerical modelling of the evolution of kinematical discontinuities within a continuous body, that can be due either to physical discontinuities between different materials or to opening of interfaces in an homogeneous phase. Although the physics of the phenomena is quite different, a common procedure can be adopted in the analysis introducing cohesive interfaces in the continuum, that obey appropriate traction-opening displacements laws. Different activation mechanisms for the interfaces have been proposed based either on the accumulation of damage in a region of the material, or on localised stress concentration at the tip of the interface. The study of the local process in a neighbourhood of the interface is a the topic of Fracture Mechanics. The study of damaging processes and of their correlation with the propagation of the interfaces, requiring larger geometries, falls within the context of Continuum Mechanics. The introduction of localised discontinuities fills the gap between the two approaches; furthermore it avoids the lack of uniqueness of the numerical solution experienced in continuum damage mechanics. However, mixed approaches based on local/non local mechanics have also been proposed. In the context of the Finite Element Method, two strategies can actually be used for introducing interfaces in the material:

**Interelement interfaces** The growth and the opening of interfaces, ruled by an activation function, is located in interface finite elements, specifying the mechanical properties and constitutive laws for the interface. In this method the propagation path has to be assigned a priori, otherwise sophisticated remeshing techniques are needed. However, the repeated topologic change in the finite elements domain reduce the computational efficiency of the method.

**Intraelement interfaces** The discontinuities in the displacement field arising across the interfaces are introduced by means of an enrichment in the finite element interpolation. They are able to capture an interface anyway oriented saving the initial discretization of the domain but a tracing technique for the detection of the interface direction is needed.

Currently two wide classes of methods based on the enrichment of the kinematics of the continuum exist for introducing intraelement strong discontinuities. The first class is characterized by the Elements with Embedded Discontinuities (EED); the second is based on the eXtended Finite Element Method (X-FEM). Although they employ the same kinematic assumptions, they differ substantially in the numerical implementation. The paper deals specifically with the EED approach that do not need additional degree of freedom. The advantages and the approximations of the method are discussed and analysed.

Main goal of the paper is to show how it is possible to include a general form of damage, ruled by an independent internal variable, in the constitutive relation for the interface. This is essential for providing a consistent transition from the continuum to the local dissipation. It requires to introduce a generalised form of the equilibrium equations, analogous to those used for estimating the tractions on the interface taking a weighted average of the stresses in the finite element. Different cases will be investigated: damage on the interface is studied either as a projection of damage in the continuum or as an independent phenomenon, coupled with continuum damage.

The relevant equations of the model are obtained from a variational principle, making use of the Enhanced Assumed Strain (EAS) concept, additively decomposing the strain into a conforming and an enhanced part. In contrast with previous embedded crack models [1], [2], [3], that implement EAS by means of a static condensation technique, in this work the numerical implementation of the algorithm is based on the formal analogy between the equations of the enriched continuum and the theory of classical plasticity, following recently developed strategies. However, contrary to [4], the L2 stress-enhanced strain orthogonality condition is not seen as a yielding condition but as equilibrium condition from witch the stress state at the discontinuity surface is determined. In this way an arbitrary activation function can be defined for the interface, depending on the traction and some set of internal variables. It is obtained a structure of the numerical algorithm that allows the use of the procedure inside classical F.E. codes for the solution of the equilibrium problem of elastic-plastic solids.

A validation of the numerical algorithm and a comparison with other procedures, including commercial codes, with regard to handiness in the implementation in standard F.E. environment, accuracy in the results and numerical efficiency will be presented.

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