Unifying damage mechanics and peridynamics for the objective simulation of material degradation up to complete failure

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Abstract: Despite many different approaches have been developed, the objective (mesh-independent) simulation of evolving discontinuities, such as cracks, remains a challenge. Current techniques are highly complex or involve intractable computational costs, making simulations up to complete failure difficult.

We propose a framework as a new route toward solving this problem that adaptively couples local-continuum damage mechanics with peridynamics to objectively simulate all the steps that lead to material failure: damage nucleation, crack formation and propagation. Local-continuum damage mechanics successfully describes the degradation related to dispersed microdefects before the formation of a macro crack. However, when damage localizes, it suffers spurious mesh dependency, making the simulation of macro cracks challenging. On the other hand, the peridynamic theory is promising for the simulation of fractures, as it naturally allows discontinuities in the displacement field.

Here, we present a hybrid local-continuum damage/peridynamic model. Local-continuum damage mechanics is used to describe “volume" damage before localization. Once localization is detected at a point, the remaining part of the energy is dissipated through an adaptive peridynamic model capable of the transition to a “surface" degradation, typically a crack.

We believe that this framework, which actually mimics the real physical process of crack formation, is the first bridge between continuum damage theories and peridynamics. This approach leverages at best both techniques as 1) damage mechanics helps in locating at low-cost where a peridynamics model should be introduced and 2) the peridynamics models helps in stabilizing the damage mechanics solution once the localization is achieved. Two-dimensional numerical examples are used to illustrate that an objective simulation of material failure can be achieved by this method.

Bio sketch: Gilles Lubineau is a Professor of Mechanical Engineering and principal investigator for COHMAS (Composite & Heterogeneous Materials Analysis & Simulation), an integrated environment for composite engineering that he created in 2009 when joining KAUST. He is also chair of the Faculty of Mechanical Engineering. Before joining KAUST, Prof. Lubineau was a faculty member at the École Normale Supérieure of Cachan, France, from which he earned a PhD degree in Mechanical Engineering & a research habilitation in Mechanics in 2008. He also served as a visiting researcher at UC-Berkeley & external faculty member at the École Polytechnique. He received the Daniel Valentin Award for best innovative works related to the field of composite materials in 2004. He is member of various Editorial boards, including the International Journal of Damage Mechanics. Over his career, Pr. Lubineau has worked on both fundamental and applied research with many companies related to non-metallic materials. He wrote more than 140 peer review papers.