Dynamic fragmentation using phase-field modelling of fracture

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Abstract

Dynamic fragmentation is a process during which a material or structure subjected to intense loads fails catastrophically through the initiation, propagation and coalescence of a multitude of cracks. It is a key topic in many fields of engineering, as for instance in aerospace industry, where the outcome of destructive re-entry is of great concern. Robust numerical models are direly needed to develop a fundamental understanding of such events, in particular to be able to predict the statistical distributions of fragment sizes, shapes and velocities resulting from destructive events.

A well established way to address this problem is to use finite elements solid mechanics models coupled with cohesive elements (1). Cohesive cracks give an explicit representation of crack surfaces and simplify the treatment of contacts between fragments, a crucial factor to predict debris velocities. However, the cohesive approach is known to suffer from mesh dependency, with crack paths that depend on the underlying mesh, resulting in non-robust predictions of fragments shapes.

Phase-field modelling of fracture belongs to another family of methods using diffuse crack approaches and, as opposed to cohesive models, where the fracture paths are not dependent on the underlying mesh. Phase-field has been shown to lead to promising results in many problems, not only in quasi-static but also in dynamics where different mechanisms such as branching can be observed (2).

Moreover, the multiplicity of possible crack patterns obtained with phase-field for a single loading case in quasi-static has been discussed in (3) where different simulation outcomes can be associated with probabilities. This study is yet to be extended to dynamic cases, where the evolution of statistics on fracture paths with the loading rate can be explored. This stochastic approach is of great interest in the context of dynamic fragmentation to enrich statistical data of fragment sizes and shapes in light of material heterogeneity.

In addition to the conventional stiffness degradation associated with damage, certain models also account for a reduction in mass density in damaged zones, as proposed in (4). It is particularly pertinent to examine the influence of this mass loss on key fracture characteristics, including crack tip velocity, damage band width, and the branching mechanism,

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as well as its broader impact on fragmentation outcomes predicted by phase-field simulations.

The phase-field approach to fracture will be evaluated in the context of dynamic fragmentation, with numerical results compared against available analytical models and the predictions of cohesive crack models. Furthermore, the influence of mass loss will be investigated, and the sensitivity of debris distributions to minor variations in material parameters or model geometry will be analysed.

References

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