Hybrid discontinuous Galerkin/cohesive zone model computational framework for dynamic fracture and fragmentation in geometrically exact slender beams

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Exceptional advances in additive manufacturing have recently enabled the development of architected materials with microstructures engineered to achieve unprecedented combinations of properties. For example, architected materials can be designed for high strength and stiffness, at a relatively low weight, or for maximizing energy absorption or dissipation in extreme events. Canonical examples of such architected materials are truss-based micro- and nanolattices, which consist of beam networks in a lattice-based repeating arrangement that have found applications in ultra-lightweight structures for load-bearing and impact absorption. Recent experimental work has shown promising application of such materials for supersonic impact resilience, surpassing kevlar and steel by an order of magnitude in energy-absorption-to-weight ratio [1].

While architected materials with relatively simple topologies can be analyzed based on fundamental approaches, predicting the response of more complex structures in extreme environments requires advanced computational modeling [2]. In fact, the response of architected materials in extreme environments is governed by various energy absorption and dissipation mechanisms, including buckling, fracture, and fragmentation [1, 3].

In this talk, we present a hybrid discontinuous Galerkin (DG)/cohesive zone model (CZM) computational framework capable of modeling buckling, fracture, and fragmentation in truss-based architected materials when subjected to extreme loading environments. The framework is developed by combining the DG discretization of the geometrically-exact large-deformation Kirchhoff beam formulation and the CZM for fracture. The flux and compatibility terms in the DG beam formulation impose continuity at the interfaces before fracture, while a CZM is used to model the fracture process at the element interfaces. An advantage of this framework is its inherent massive parallel scalability, which was demonstrated both in case of dynamic [4] and quasi-static [5] fracture propagation, thus allowing large scale fracture simulations for realistic applications.

Finally, we present numerical results demonstrating the ability of the hybrid discontinuous Galerkin (DG)/cohesive zone model (CZM) framework to capture the relevant physics in beam-based structures exposed to extreme environments.

References

[1] Carlos M Portela, Bryce W Edwards, David Veysset, Yuchen Sun, Keith A Nelson, Dennis M Kochmann, and Julia R Greer. Supersonic impact resilience of nanoarchitected carbon. *Nature Materials*, 20(11):1491–1497, 2021.

[2] Dennis M Kochmann, Jonathan B Hopkins, and Lorenzo Valdevit. Multiscale modeling and optimization of the mechanics of hierarchical metamaterials. *MRS Bulletin*, 44(10):773–781, 2019.

[3] Xiaoyu Zheng, William Smith, Julie Jackson, Bryan Moran, Huachen Cui, Da Chen, Jianchao Ye, Nicholas Fang, Nicholas Rodriguez, Todd Weisgraber, et al. Multiscale metallic metamaterials. *Nature materials*, 15(10):1100–1106, 2016.

[4] Raúl Radovitzky, Andrew Seagraves, Mike Tupek, and Ludovic Noels. A scalable 3d fracture and fragmentation algorithm based on a hybrid, discontinuous galerkin, cohesive element method. *Computer Methods in Applied Mechanics and Engineering*, 200(1-4):326–344, 2011.

[5] Bianca Giovanardi, Santiago Serebrinsky, and Raúl Radovitzky. A fully-coupled computational framework for large-scale simulation of fluid-driven fracture propagation on parallel computers. *Computer Methods in Applied Mechanics and Engineering*, 372:113365, 2020.