Séminaire général de mécanique de l'Institut Polytechnique de Paris

Recent results on variational phase-field modeling of cohesive fracture

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Abstract

Variational phase-field models of brittle fracture have been quite successful for studying Griffith-type crack propagation in complex scenarios. However, as approximations of Griffith's theory—which does not incorporate a strength criterion—these models lack flexibility in prescribing material-specific strength surfaces. Consequently, they struggle to accurately capture crack nucleation under multiaxial stress conditions.

In a recent paper [1], we proposed a variational phase-field model that approximates cohesive fracture and accommodates an arbitrary (convex) strength surface, independent of the regularization length scale. This formulation results in sharp cohesive cracks and naturally enforces a sharp non-interpenetration condition. It satisfies strain hardening for a sufficiently small ratio of the regularization length to the material's cohesive length, whereas stress softening and "crack-like" residual stresses are fulfilled by construction. In [1], we investigated the model in one and three dimensions, establishing first- and second-order stability results.

More recently [2, 3], we have made further progress in different directions. From the modeling standpoint, we have clarified pros and cons of different strength criteria, including those considered in [1] and [4], and we have compared the results of the second-order stability analysis in [1] with the partially contradictory results in [4] and with numerical experiments. From the computational standpoint within the finite element method, we now solve for the eigenstrain locally by means of closed-form or one-dimensional numerical iterative solutions, which enables the straightforward extension of codes based on phase-field models of brittle fracture to the new framework. Finally, we have extended the model to dynamics [4] and examined the main features of its behavior regarding interaction of elastic waves with pre-existing cracks and crack propagation. The talk summarizes these recent advancements.

REFERENCES

[1] F. Vicentini, J. Heinzmann, P. Carrara, L. De Lorenzis (2026), Variational phase-field modeling of cohesive fracture with flexibly tunable strength surface, Journal of the Mechanics and Physics of Solids, 207, 106424.

[2] G. Illiano, F. Vicentini, L. De Lorenzis (in preparation).

[3] J. Heinzmann, F. Vicentini, P. Carrara, L. De Lorenzis (in preparation), Variational phase-field modeling of dynamic cohesive fracture.

[4] B. Bourdin, J. Marigo, C. Maurini, and C. Zolesi (2025), A variational approach to fracture incorporating any convex strength criterion. arXiv:2506.22558.

About the speaker

Laura De Lorenzis is Full Professor of Computational Mechanics at the ETH Zürich. Prof. De Lorenzis and her group develop mathematical models and computational methods and perform experiments to observe, describe and predict complex phenomena involving the mechanics of solid materials. In 2022 she was elected Solid Mechanics Fellow of the European Mechanics Society (EUROMECH) "in recognition of her outstanding and influential contributions to computational solid mechanics including in particular phase-field approaches to fracture and fatigue, variational collocation methods, and data-driven mechanics".

Seminar webpage link