Emergent Size Effects in Continuum Damage Modeling of Brittle Fracture with Under-Resolved Crack-Tip Stresses

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Continuum damage approaches allow for robust treatment of brittle damage and are well-suited to applications coupling damage, fracture, fragmentation, and large deformation. Assigning a Weibull-distributed initial strength in a simulation hides certain mesh dependencies of failure patterns and allows the stress at which damage initiates to have an emergent size effect and variability that is independent of the resolution of the discretization[1]. However, the weakest-link assumption underlying Weibull theory will not be realized unless the stress field around the first failed particle is resolved sufficiently to represent the stress around a crack with a size equal to that of the failed element. Two approaches are presented to correct this limitation, (i) a dual discretization approach where Weibull-varying strength is assigned to clusters of particles, such that the stress field around the first critical flaw is better resolved, and (ii) a crack-tip stress concentration correction to account for the under-resolution of stress when the element size is far greater than the crack-tip (or fracture process zone) radius. We demonstrate these approaches in a material point method (MPM) framework[2] and show that the expected statistical variability and size effects of strength[3] can be achieved for a number of fracture cases, including both strength-dominated and toughness-dominated failure, and that the framework is robust for extreme deformation cases and tolerant of coarse mesh resolutions. Limitations of the method and unresolved challenges will be discussed.

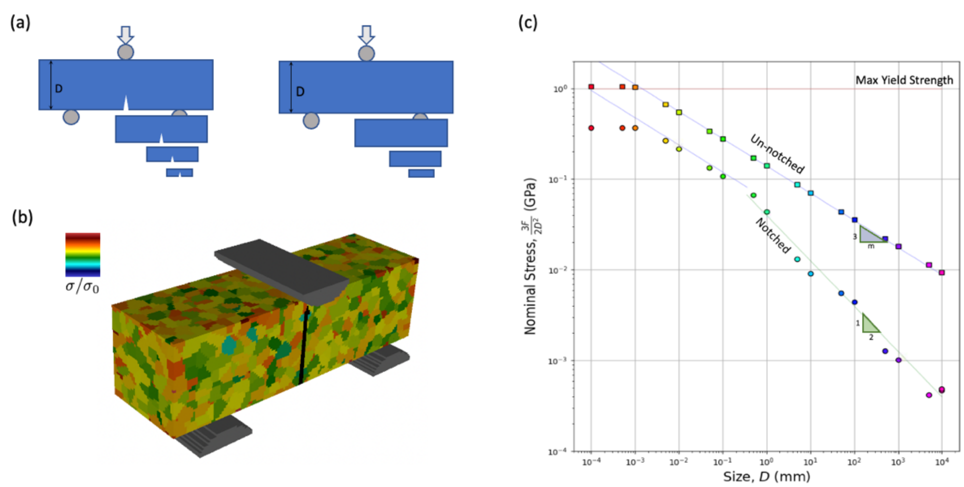

Figure 1 Emergent size effect in strength- and toughness-dominated failure using new approach for spatially correlated strength distribution and crack-tip stress enhancement.

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[2] Homel, Michael A., and Eric B. Herbold. "Field-gradient partitioning for fracture and frictional contact in the material point method." *International Journal for Numerical Methods in Engineering* 109, no. 7 (2017): 1013-1044.

[3] Bažant, Zdeněk P., and Qiang Yu. "Universal size effect law and effect of crack depth on quasi-brittle structure strength." *Journal of engineering mechanics* 135.2 (2009): 78-84.