Advances in Experimental Fracture Mechanics: Applications to Fragmentation and Cratering.

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Introduction: Classical predictions of fragment size resulting from dynamic fracture events (e.g., Grady-Kipp [1]) tend to overestimate fragment sizes for events occurring in the intermediate to low strain rate regime that often occur in celestial impacts. Recent advances in dynamic fragmentation theory [2], [3] offer improved fragment size predictions by incorporating defect distribution/evolution effects and the dynamics of the failure process. We plan to study the scope of implementing these improvements using dynamic impact experiments on the laboratory scale that will provide verification of the recent theoretical advances as well as data that will then be used to anchor the numerical simulations of large-scale impact events of interest to the planetary sciences community. We also expect to gain insights into how to scale these new advances to planetary cratering.

Method: Prior and current experimental studies of asteroid fragmentation and impact cratering have focused on conducting experiments that directly simulate planetary-like impact events but at the laboratory scale [e.g., 4]. The experimental results were then combined with scaling laws to predict behavior on larger scales. The approach to be used here is different.

Following the work of Paliwal et al. [5], the experiments will be conducted on a simplified geometry, to enhance our physical understanding of the interplay between strain rates experienced by a target and defect distribution when considering geological materials. The approach will consist of using the set-up shown in Figure 1 to subject the test specimen to a dynamic, uniform, one-dimensional compression at low to intermediate strain rates (10^1-10^2 s^{-1}). Such rates are comparable to what asteroids and planets experience during large scale impacts. High speed imaging will be used to track the evolution of damage during the failure process with temporal resolution on the microseconds time scale. The elastic bar and strain gage act as a dynamic load cell allowing for the loading history to be correlated with the observed damage evolution. Postmortem analysis of the resulting fragments will also be performed to determine the fragment size distribution.

Since the specimen deforms under uniaxial compression—as opposed to the more complex state of stress generated in a small impactor/large target experiment—the effects of strain rate and defect density are more readily investigated. The proposed experiments will be performed on transparent quartz specimens, a material that is relevant to planetary/ geologic fragmentation. Plans to prepare specimens with user-introduced internal defects [6] are also under consideration, allowing for better control over the initial flaw distribution.

The fracture parameters determined in the above experiments will be incorporated into numerical simulations using the Eulerian code CTH. This sophisticated code can then be used to simulate more complex laboratory impact experiments verifying robustness of the new additions to the code. One such experiment is the two-dimensional plane-strain cratering problem in which a cylindrical projectile is launched into a large quartz target approximating impact on a half-space. The resulting images and postmortem measurements of crater/ejecta size can then be compared with the predictions of the numerical simulations.

The combination of the experiments and numerical work will provide the basis for the development of new scaling rules for asteroid and planetary cratering that can enhance our understanding of the evolution of these objects.

References: [1] D.E. Grady and M.E. Kipp (1985), *Mechanics of Materials, 4, 311-320.* [2] F.H. Zhou, J.F. Molinari, and K.T. Ramesh (2005), *International Journal of Fracture, 139(2), 169-196.* [3] B. Paliwal and K.T. Ramesh (2008), *Journal of the Mechanics and Physics of Solids, 56, 896-923.* [4] K.R. Housen and K.A. Holsaple (1999) *Icarus, 142, 21-33.* [5] B. Paliwal, K.T. Ramesh, and J.W. McCauley, *Journal of the American Ceramic Society, 89(7), 2128-2133.* [6] Y.Z. Li, M.P. Harmer, and Y.T. Chou, *Journal of Materials Research, 9(7), 1780-1788.*

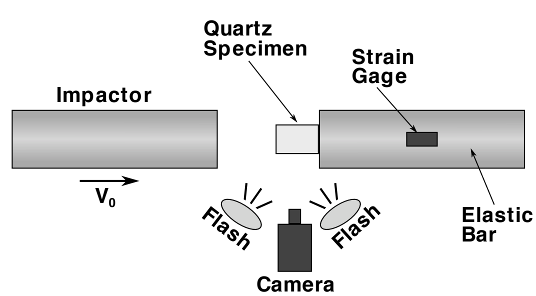

Figure 1. Schematic of the proposed experimental setup detailing key components (not to scale).