HYPERVELOCITY IMPACT AND DYNAMIC FRAGMENTATION OF BRITTLE MATERIALS. V. Agrawal[1], A. L. Ortega[2] and D. M. Meiron[3], [1]Aerospace Engineering, Auburn University (vza0013@auburn.edu), [2]Electric Propulsion Group, Jet Propulsion Laboratory, [3]Aerospace Engineering, California Institute of Technology.

In this work, we study high velocity impact induced dynamic fragmentation process of brittle materials. The process of hypervelocity impact and dynamic fragmentation finds application in planetary formation, satellite design for micrometeorite impact damage mitigation, armor design and crater formations. We implement the ideas of Continuum Damage Mechanics (CDM), which borrows its core from plasticity and introduces a fictitious undamaged configuration using a damage deformation tensor [1-4].

The damage formulation is implemented on an existing computational framework, AMROC (Adaptive Mesh Refinement in Object oriented C++) capable of adaptive mesh refinement, operating on a fixed computational grid [5-7]. This approach avoids problems associated with conventional solid mechanics simulations such as grid entanglement and re-meshing observed under large deformation processes. AMROC solves conservation laws in full finite deformations using deformation tensors and overcomes problems associated with small strain approximations of large deformations. Further the framework employs a level set configuration that tracks the motion of sharp interfaces. This provides greater resolution of interfaces and doesn't require diffusing interfaces over computational cells. This framework has been used in the past to study ductile materials [8] and even Richtmyer-Meshkov instabilities [9-10].

We use this framework to perform fragmentation simulations on brittle materials with different geometries. A damage sensitive equation of state is developed for hyper-elastic materials that depends on the damage deformation tensor. To restrict the analysis to dynamic fragmentation, the damage deformation tensor was expressed purely as a function of a damage variable D, the volume fraction of micro-cracks in the brittle material. Here D represents the degradation of the material, and acts by lowering material moduli. A modified, thermodynamically consistent Grady-Kipp fragmentation model [11-12] is used that evolves damage at the points of tensile eigenvalue stresses. The evolution law involves an effective damage-Mandel stress and a static strength that depends on Weibull parameters and bulk crack speed. The Weibull parameters connect the macroscopic strain to the number of flaws and their size on a microscopic scale. Further, the brittle material is capable of undergoing brittle-ductile phase transition.

We study damage propagation in simplified geometries such as sphere-on-sphere and sphere-on-plate impact processes with combination of ductile and brittle materials at different impact speeds. Contributions of various processes like strain-hardening, melting, rate-dependent plasticity and pressure dependent yield strengths are studied in the fragmentation process. We validate our calculations with existing literature. This work promotes development of damage laws in context of fracture energy dissipation using a novel framework capable of studying finite deformations in materials.

References: [1] Lemaitre, J., *J. Eng. Mat. Tech.*, 107-1 (83), 1985. [2] Voyiadjis, G.Z. and Taehyo, P., *Int. J. Eng. Sci*, 37-7 (803), 1999. [3] Bruinig, M. *Int. J. Eng. Sci.*, 39-9 (1033), 2001. [4] Balieu, R. and Kringos, N., *Int. J. Plas.*, 70 (126), 2015. [5] Deiterding, R., *Adaptive Mesh Refinement – Theory and Applications*, 41 (361), 2005. [6] Barton, P.T. and Drikakis, D., *J. Comp. Phys.*, 229-15 (5518), 2010. [7] Barton, P.T. *et al.*, *J. Comp. Phys.* 240 (76), 2013. [8] Ortega, A.L., *et al.*, *J. Comp. Phys.*, 257 (414), 2014. [9] Ortega, A.L., *et al.*, *JMPS*, 76 (291), 2015. [10] Ortega, A.L., *et al.*, *Phys. Rev. E*, 89 (033018), 2014. [11] Grady, D.E. and Kipp, M.E., *Int. J. Rock Mech. Min. Sci.*, 17-3 (147), 1980. [12] Melosh H.J., *et al.*, *J. Geophys. Res. – Planets*, 97 – E9 (14735), 1992.