REAL-TIME OBSERVATION OF EARLY STAGE DAMAGE DURING HYPERVELOCITY IMPACTS INTO BASALT TARGETS.

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Introduction: Many studies of hypervelocity impact disruption and /or cratering are predominantly focused on the late stage behavior, e.g. remnant fragment mass [1, 2], or transient crater shape [3, 4]. These late stage phenomena are dominated by the interaction of multiple release waves and simulations of these events often ignore damage accumulation at very early stages when compressive stress states dominate. This damage induced at early times alters the state of the material that is subjected to subsequent loading and may significantly affect the outcome of impact events. It is critical to understand the failure processes and associated damage accumulation throughout all stages of an impact event.

Experimental Method: In order to investigate the failure processes active during the early stages of a hypervelocity impact, we adapt a specimen geometry similar to that used by Guiberteau et al. [5] in which Hertzian indentation experiments were conducted along the interface of two bonded plates. The use of two bonded plates allowed for the damage accumulation under the indent to be examined postmortem by unbonding the two plates.

For our experiments, hypervelocity impacts were conducted by launching 6.35mm glass spheres at velocities of 1-5km/s using the vertical gun range at NASA Ames. The targets were 100x100x50mm plates of basalt and glass adhesively bonded together to allow for the investigation of damage development in regions near the impact site. The configuration consisted of a basalt plate bonded to a glass plate resulting in a cube shaped specimen 100mm on each edge (Figure 1(a)). The specimens were arranged so that the damage front propagating along the basalt/glass interface could be visualized in real-time using ultra-high-speed photography after impacting the top surface at the interface Figure 1(b). Real-time visualization allows for damage development to be examined under conditions where the loading history is well known, as opposed to post-mortem evaluation of damage [6], where wave interactions lead to complex stress states.

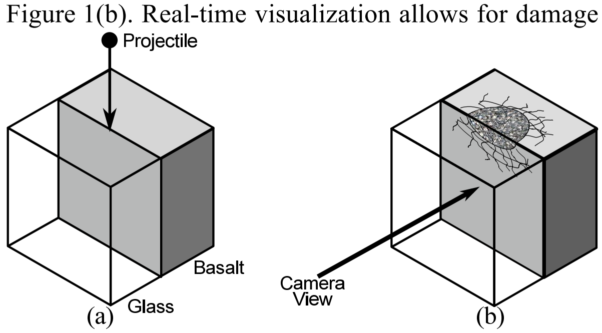

Figure 1. Schematics of: (a) bonded basalt/glass specimen, (b) bonded basalt/glass specimen showing camera location to view damage through glass.

Results: Images captured at an interframe time of 2 μs and exposure time of 500 ns during a 3 km/s impact on a basalt/glass target are shown in Figure 2. The impact was located on the basalt side at a distance 10 mm perpendicular to the interface. Figure 2(a) was captured at the moment of impact (t = 0 μs) and the projectile can be seen making contact with the upper surface of the specimen. Figure 2(b) was captured 10 μs after impact, and shows the ejecta plume rising from the top of the specimen, as well as some damage below the impact site. Also shown are lines corresponding to the dilatational and shear wave packets generated by the impact. The leading (loading) and trailing (unloading) edges of the dilatational wave are marked by the yellow semi-circular lines that expand radially along the basalt/glass interface at the dilatational wave speed of the basalt c_d=4,310 m/s. The red semi-circular lines denote the locations of the loading and unloading fronts of the shear wave packet generated by the impact. These travel at the shear wave speed of basalt c_s=2,577 m/s. Figure 2(b) also shows a zone of damage that is trailing the unloading front of the dilatational wave. This damage zone continues to grow as can be seen in Figure 2(c), captured 14 μs after impact. In fact, it appears that damage develops in two distinct zones. The first is damage along the interface denoted by the dark grey region directly behind the dilatational unloading front. The second zone is the brighter region that is closer to the impact site, corresponding to damage in the glass. We note that there is significant damage to regions under the impact site which have not been loaded by tensile waves generated by reflections at specimen boundaries. Figure 2(d) was captured 18μs after impact and shows that the dilatational wave packets have reflected from the lateral specimen boundaries and are now traveling into regions of prior damage. The propagation of interface damage (dark grey region) has slowed and significantly trails the dilatational wave packet. The central area of damage in the glass is now being overtaken by the shear wave packet and begins to localize. This localization manifests as a roughening of the failure front, where the damage growth rate along the front becomes less uniform. These localized regions of dam-

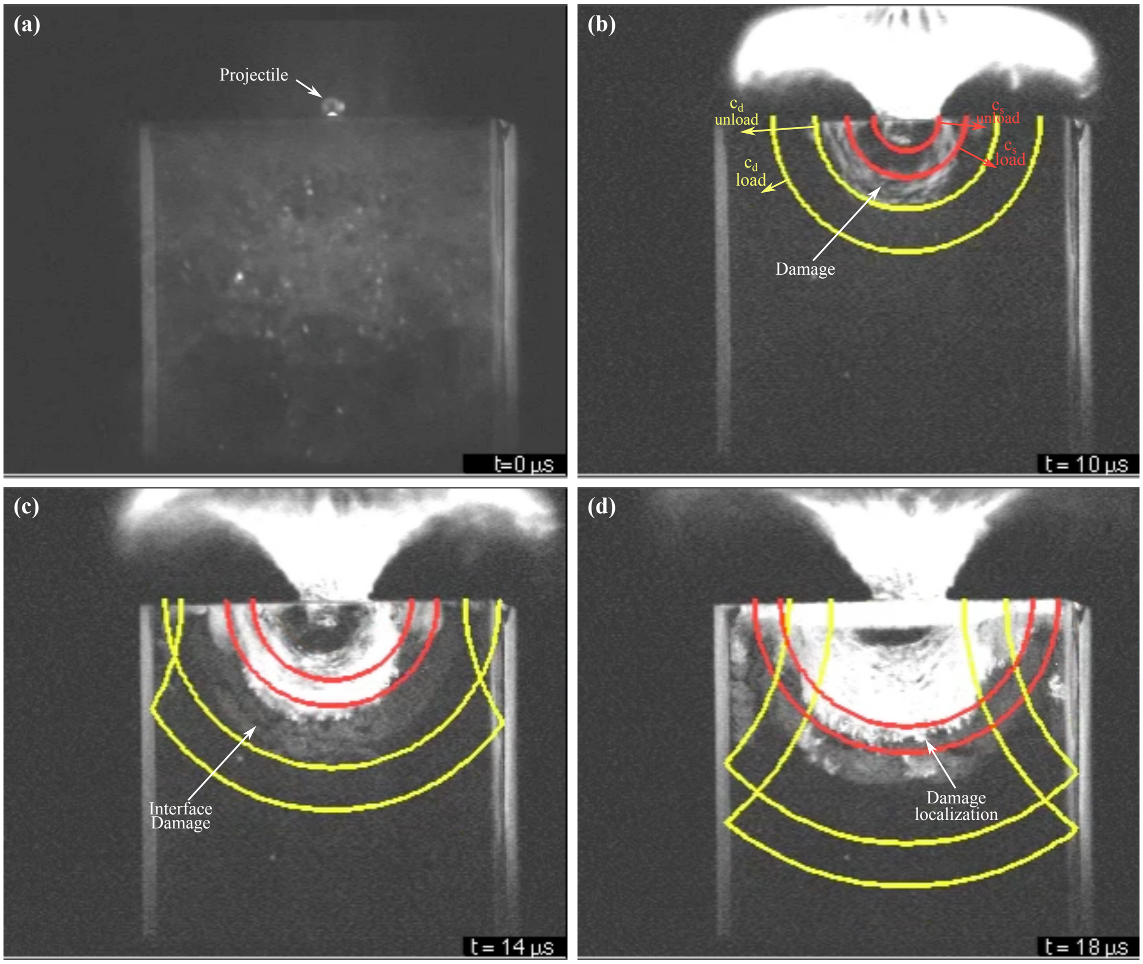

Figure 2. High-speed images captured during a 3 km/s impact on a basalt/glass target. Camera is aligned so that view is through the glass focusing on the interface between the two materials.

age will significantly affect the response of the system to subsequent wave reflections or reloading.

Discussion: The experiment presented above shows that significant damage accumulates early in the impact process (i.e. before tensile reflections from boundaries). This highlights the need for material models that are able to capture the damage accumulation under the stress states (compression and shear) that dominate the early times of impact processes, as well as growth of previously damaged regions subjected to subsequent loadings. In other words, these material models need to capture the entire history of the impact event and account for multiple modes of damage growth. To that end, the detailed evolution of damage captured by our experiments provides a useful tool for material model development. The advanced material models can then be utilized to simulate the response of bodies that have undergone multiple impacts such as Eros. These simulations will provide insight into the evolutional history allowing for the comparison of plausible impacts to be correlated with the existence of large impact craters (Himeros, Psyche) and surface linements [7]. Accounting for damage accumulated at early stages of impact may also play a critical role in determining final impact crater morphology and improve our understanding of the simple-to-complex crater transition.

The type of experiment described above also provides a means for validation of existing numerical codes used to study planetary impacts. As the fidelity of numerical simulations increases due to increased computing power, experiments that elucidate the details of material failure at finer temporal and spatial resolution will be required for validation.

References:

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