

## COMPUTATIONAL EXAMINATION OF DEFORMATION WAVE-BOUNDARY INTERACTION FOR GRANULAR EXPLOSIVE

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### ABSTRACT

Experiments have shown that the interaction of deformation waves propagating through heterogeneous energetic solids with confining boundaries can result in combustion of these materials. Wilson, et al. [1], observed ignition at an anvil-explosive interface while loading an explosive with shock levels below the plane shock initiation threshold. These observations are of practical significance since most explosive hazards and accident scenarios involve inadvertent loading of the material and complex wave-boundary interactions.

Though the loading of granular explosives by planar deformation waves has been studied extensively, the analysis of complex wave-boundary interactions has received comparatively little attention. To this end, we numerically investigate the interaction of an initially planar deformation wave with a curved boundary. The bulk hydrodynamic compaction model studied here is based on a continuum mixture theory and accounts for energy dissipation due to volumetric deformation [2]. Material properties chosen for the study are representative of the well characterized granular high explosive HMX ( $C_4H_8N_8O_8$ ).

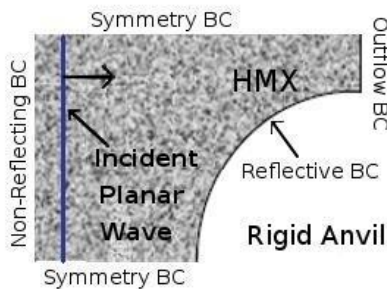


Figure 1: Schematic of the domain and Boundary Conditions (BCs) used in the numerical study.

The model problem is depicted in Fig. 1. A planar incident wave travels through the domain from left to right and collides with the rigid anvil surface. The wave is initialized in the domain by using spatial variation of density, pressure, velocity, and volume fraction, obtained from the solution of the steady state form of the governing

equations in one dimension. Boundary conditions imposed are indicated in the figure. Unnecessary computational effort has been avoided by taking advantage of the symmetry of the problem. The hyperbolic system of governing equations is solved using a Total Variation Diminishing (TVD) high-resolution shock capturing method formulated by Kurganov and Tadmor [3]. The numerical code used in the study has been verified with standard gas dynamics problems and steady solutions for hydrodynamic compaction waves.

Representative predictions are given here for a particular case where the initial solid volume fraction of

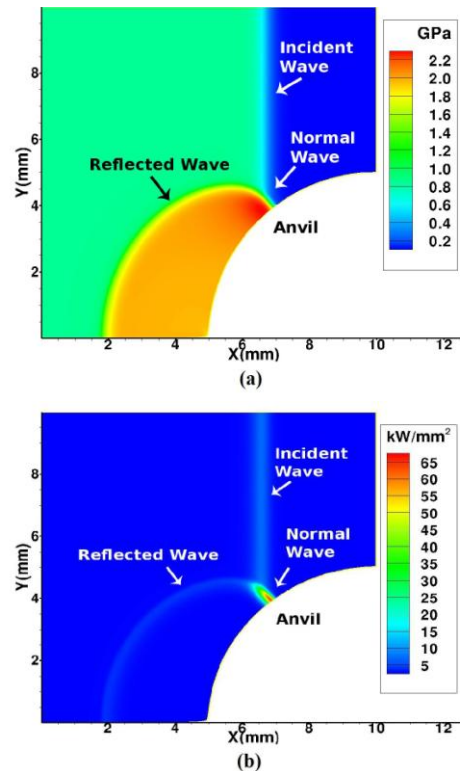


Figure 2: Contours of the (a) solid pressure and the (b) grain scale heat flux at  $t = 4.85 \mu s$ .

HMX is 0.85 (15% porosity) and the initial wave structure corresponds to an impact speed of 300 m/s. The average grain size of HMX is 200  $\mu\text{m}$ . As shown in Fig. 2, the impact between the incident wave and the rigid anvil sends out a reflected wave. The reflected wave travels through the material pre-compacted by the incident deformation wave, bringing it to a final equilibrium state corresponding to very little porosity. Following impact, a more complex wave structure develops which consists of a wave normal to the anvil boundary to maintain flow tangency near the anvil surface. At this point, an incident wave, a reflected wave and a normal wave coexist at a single point similar to a Mach stem in gas dynamics. The normal wave strengthens as it accelerates along the boundary before weakening. This feature can also be noticed in Fig. 3 where we present the evolution of solid pressure ( $P_s$ ) and grain surface heat flux ( $q$ ) with time along both the lower boundary and the anvil boundary. In these plots the solid lines represent incident wave solutions and broken lines represent reflected wave solutions. In Fig. 3(a), we can see solid pressure reaches a maximum of 2.5 GPa for  $x = 6$  mm at  $t = 3.8$   $\mu\text{s}$ . Similarly, we notice in Fig. 3(b) that the heat flux reaches a maximum of 70  $\text{kW}/\text{mm}^2$  at  $t = 4.85$   $\mu\text{s}$  near  $x = 7$  mm. A thinner structure in the heat flux plots is indicative of a stronger wave.

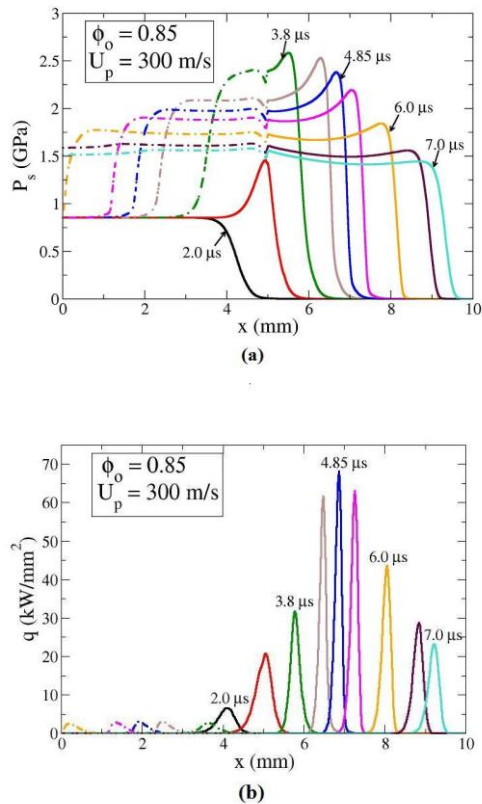


Figure 3: Evolution of the (a) solid pressure and the (b) grain scale heat flux along the lower boundary and the anvil surface at different time instants.

Our predictions, shown in Fig. 2, are consistent with the experimental observations of Wilson, et al., [1] which indicate that maximum heating occurs around the same region near the anvil surface. The incident wave structure and the shape of the anvil can play important role in material ignition. The initial wave structure is characterized by the impact speed. The initial porosity of the material dictates sensitivity of the material to impact. Hence, we are studying the dependence of thermomechanical response of granular explosives on a key non-dimensional parameter, the ratio of the incident wave thickness to the anvil radius, for different initial porosities of HMX. The results obtained from this bulk scale analysis will then be coupled with meso-scale simulations to find out the distribution of hot spot mass fraction. Hot spot formation is a key mechanism for combustion initiation in granular explosives.

### ACKNOWLEDGMENTS

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### REFERENCES

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