Elastic-Plastic Response of HMX

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A high performance explosive used in weapons applications is HMX (cyclotetramethylene-tetranitramine). Its properties are needed for meso-scale simulations of hot-spot ignition intended to guide the development of burn models. A single crystal of HMX is very insensitive and can be treated as an inert. Consequently, measurements of shock wave profiles can be used to infer its elastic-plastic properties.

A series of plate impact experiments with single crystal HMX have been performed by Jerry Dick and Dan Hooks in the Dynamic Experimentation Division (DX-2) at Los Alamos National Laboratory. The experiments, sketched in Fig. 1, used a gas gun to launch a projectile that on impact drives a strong compressive wave into an HMX sample. The principal diagnostic is a VISAR (Velocity Interferometry System for Any Reflector) measurement that records the Lagrangian-velocity time history at the sample-window interface. The time evolution of the wave profile is determined by repeating the experiment with different sample lengths. This gives information about the rate dependence of the plastic strain. Other experiments with different crystal orientations determine the anisotropic response of the crystal. In addition, experiments were performed with different shock strengths.

The wave profiles, shown in Fig. 2 for shock stress of 1.4GPa, display a characteristic elastic-plastic response. The dominant features are a shock-like elastic wave followed by a dispersed plastic wave. Moreover, the amplitude of the elastic wave decays with the distance the wave propagates. This wave behavior can be described with a rate-dependent elastic-plastic model. Moreover, the experiments show that the amplitude of the elastic wave varies with crystal orientation by a factor of about 2. Consequently, the response of an HMX crystal is strongly anisotropic.

The key elastic-plastic material parameters are the shear modulus, yield strength and plastic time constant. These parameters are determined by fitting an elastic-plastic model to the VISAR data. A solution to the model corresponding to an experiment must account for the impedance mismatch when the wave in the sample passes through to

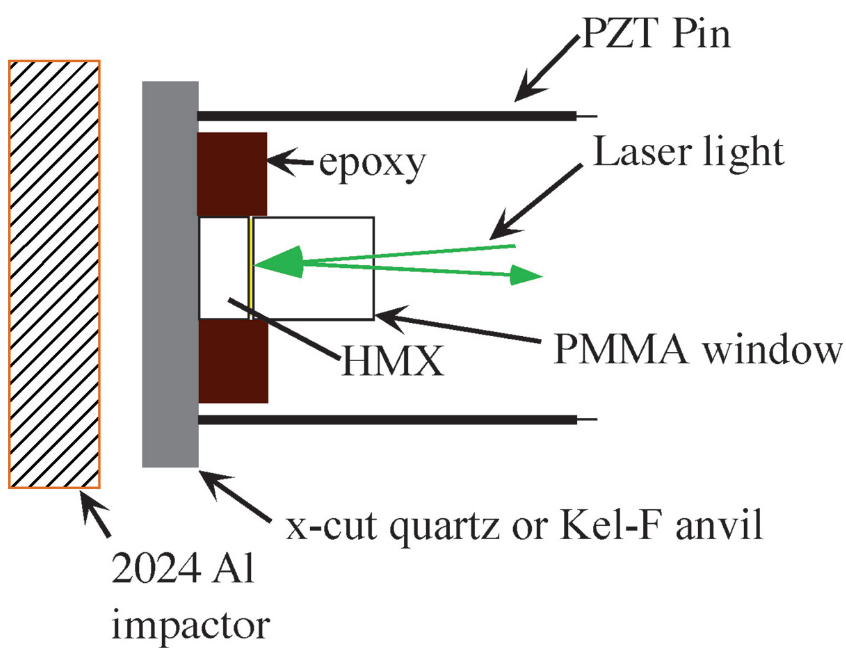

Figure 1— ***Schematic of wave profile experiments of Dick and Hooks. VISAR data corresponds to the Lagrangian time history of the HMX/PMMA interface.***

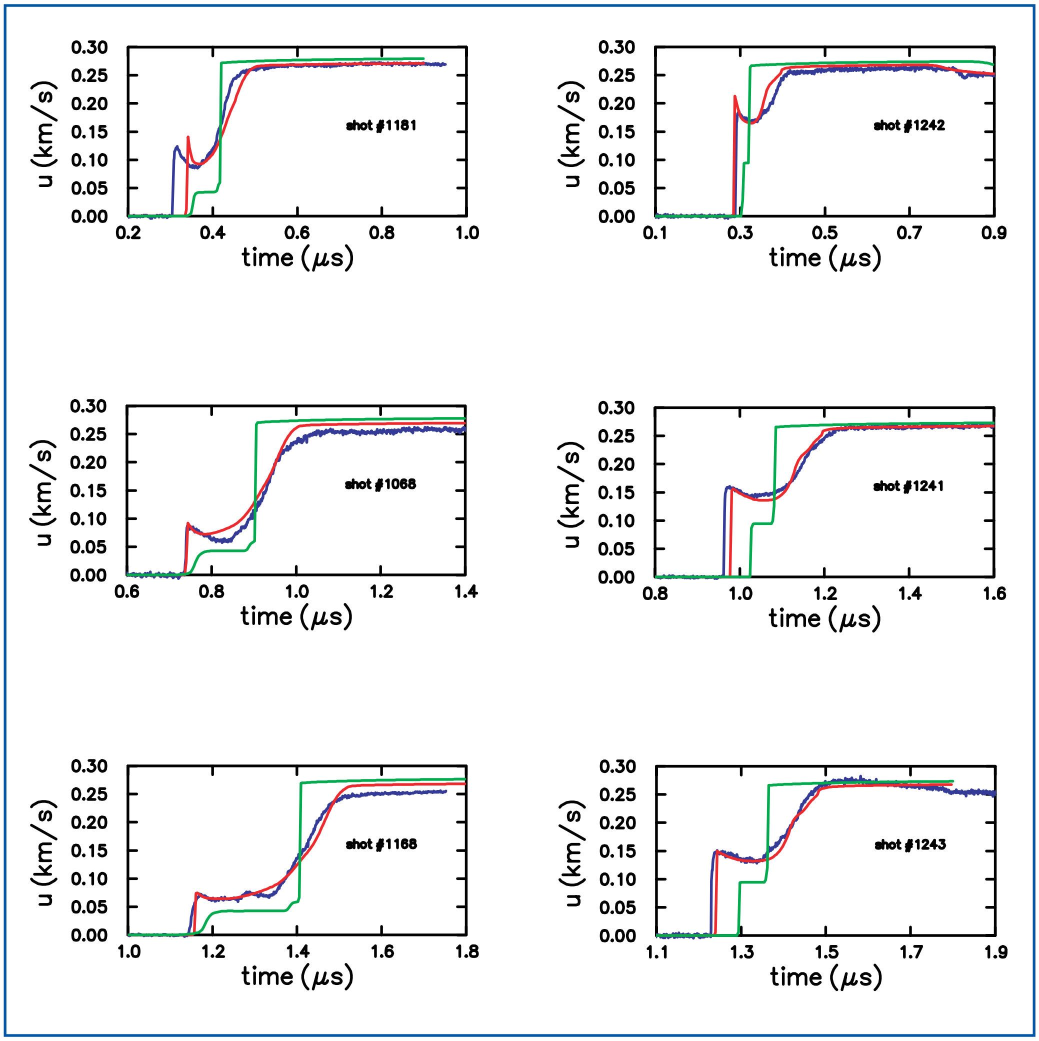

Figure 2— ***Comparison with VISAR data for shock pressure of 1.4GPa. A. (011) orientation with sample lengths of 1.39, 3.00, and 4.66 mm, respectively. B. (010) orientation with sample lengths of 1.04, 3.49, and 4.40 mm, respectively. Blue curve is experimental data from Dick and Hooks. Red and green curves are simulations with elastic-plastic model for rate-dependent and rate-independent plasticity, respectively.***

the window. The wave interaction is highly nonlinear, and an analytic solution is not possible. Instead numerical simulations are performed, and the model parameters varied until the simulated VISAR data best match the experimental data [1]. A comparison between simulated and experimental data are shown in Fig. 2.

[1] R. Menikoff, J.J. Dick and D.E. Hooks, "Analysis of Wave Profiles for Single Crystal Cyclotetramethylene Tetranitramine," *J. Appl. Phys.* **97**, 023529 (2005).