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ISENTROPIC COMPRESSION STUDIES OF ENERGETIC COMPOSITE CONSTITUENTS

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Abstract. A series of quasi-isentropic magnetic pulse compression experiments using the Sandia Z accelerator and DICE small pulser have provided new insights to the material behavior of various constituents typically used in energetic composites. In this study, a combination of forward and backward procedures with optimization software is used to determine appropriate constitutive and EOS property data. Sensitivity analysis is performed to assess the uncertainties of the experimental measurements and the subsequent effects in determining material response. The data interrogation technique was applied to a series of tests with ramp loading condition to 50 Kbar over duration of ~500 ns for panel configurations containing explosive crystals (HMX and RDX), binders (Estane, C7-Teflon, Kel-F and THV) and composites (PBS9501, PBX9502, and Al/Teflon).

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INTRODUCTION

Energetic materials often consist of explosive crystals and/or metallic constituents that are bonded together using polymer binders and the mechanical response of the resulting composite involves the interaction of materials that occurs at the mesoscale. Recent magnetic compression studies have been used to interrogate the material behavior of various energetic composite constituents toward determining the appropriate constitutive and equations of state data that is needed in detailed mesoscale modeling [1]. This study combines an experimental study with data analysis to unravel the mechanical response for a broad class of materials subjected to isentropic magnetic compression loading using the Sandia Z machine and the DICE small pulser.

EXPERIMENTAL CONFIGURATIONS

A multi-panel ICE configuration has been used in this series of tests and details of the experimental setup are discussed in Reference [2]. Additionally, the data analysis of material response is based on forward and backward techniques using CTH/DAKOTA shock physics and optimization software as outlined in Reference [3]. Various explosive constituents have been subjected to ramp loading in tests Z1251, Z1444, Z1405, Z1489 and Shot 73 on the DICE pulser to provide an extensive database of material response data.

Panel configurations were designed to incorporate thin sections of Estane, C7-Teflon, Kel-F(81 & 800), THV 220 binders, monolithic crystals of HMX(100&110), RDX(100&210), and various composites such as PBX9501, PBS9501, PBX9502 and Al/Teflon. Multiple VISARS were used to measure particle velocities at the sample/window interface and at rear surface of the drive plate. (Backward integration is used to determine the drive loading conditions [4].) The magnetic compression loading in these tests were similar and consisted of a ramp to ~50 Kbar over 300-500 ns. In the sections to follow, select materials from these tests are discussed and the optimization methodology for assessing material response is illustrated.

Z1444 – ESTANE & COMPOSITES

In Z1444 the ICE configuration consisted of a panel containing 2 samples of Estane (0.378 and 0.601 mm) and 2 samples of hydrolyzed Estane (0.370 and 0.649 mm). Multiple VISARs measurements were taken for each sample; hence, data analysis addressed optimization and sensitivity assessment. The remaining panels had samples of PBS9501, Al/Teflon and one panel contained samples of Dynon THV 220 and a composite of THV/B.

The uncertainties in drive measurements are shown in Figure 1 whereby individual VISAR uncertainties in particle velocities (σ~0.01 km/s) and panel-to-panel variations (σ~0.05 km/s) are estimated. Sample thickness was measured to within ~5μm. Material response is estimated with these uncertainties assuming a Mie-Grüneisen (M-G) form and a comparison of the optimized fit to measured particle velocity is shown in Figure 2. The optimization and Latin-hypercube sensitivity analysis for the Estane materials, $\rho_0 = 1.191$ [g/cc], did not include any strength effects and the EOS is fit according to the quadratic form of the Hugoniot

$$U_s = c_0 + s_1 u_p + s_2 u_p^2 / c_0 \quad (1)$$

where $c_0 = 1.914 \pm 0.018$ [mm/μs], $s_1 = 0.2889 \pm 0.015$ and $s_2 = -0.813 \pm 0.0445$.

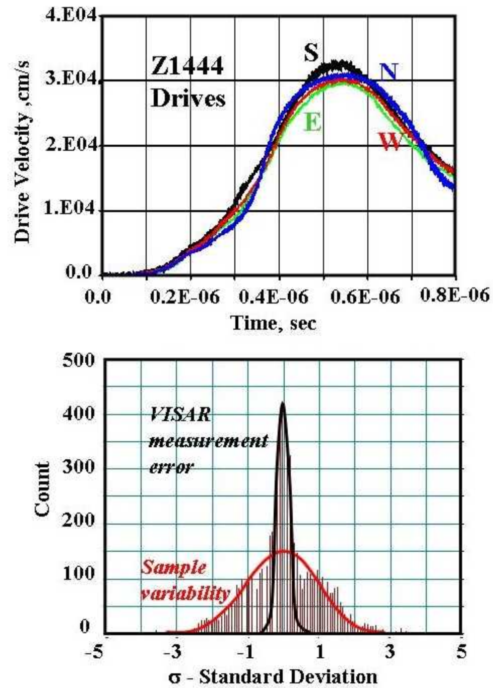

FIGURE 1. Drive measurements for each panel (top) and variations of measurement (bottom).

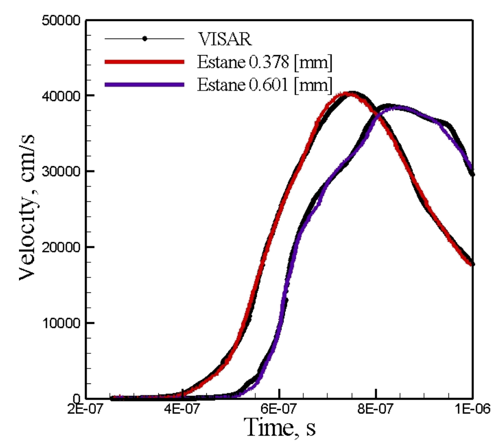

FIGURE 2. Particle velocities in the Estane samples subjected to Z1444 ramp load. CTH calculations are overlaid with the VISAR measurements.

The material response of Al/Teflon, PBS9501 and the THV/B composites were also optimized with similar agreement. These optimizations are not discussed here.

Z1405 – BINDER MATERIALS

In this test configuration various binder materials were mounted on 0.6 mm thick Al drive plates consisting of samples of Estane/BNP, C7-Teflon, HTPB, Kel-F 800 and Kel-F 81. Most of panels used LiF (100) windows except one C7-Teflon sample that incorporated a PMMA window.

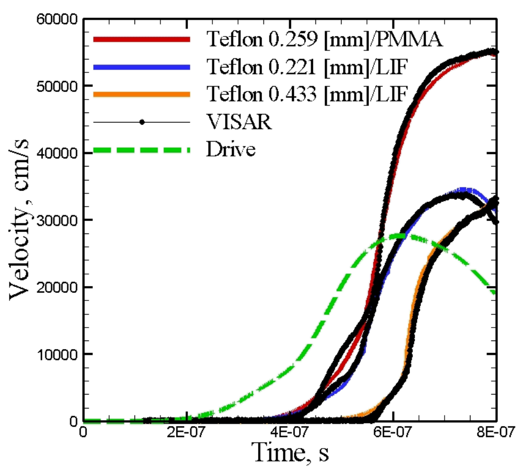

FIGURE 3. Particle velocity profiles in C-& Teflon of varied sample thickness (in mm). CTH calculations without material strength effects are overlaid.

For the panel containing the C7-Teflon samples, a quadratic M-G EOS (Equation 1) is asumed in this optimization. The undisturbed density is fixed at 2.153 g/cc and the Grüneisen parameter is taken as $\Gamma_0 = 0.59$. The CTH/DAKOTA optimization produces the parameters $c_0 = 1.41$ [mm/μs], $s_1 = 2.32$ and $s_2 = -0.213$.

RDX (100&210) AND PBX 9502

In Z1489 and Shot 73 using the small pulser, panels were configured with samples of RDX (100&210) crystals and a comparison of the material response from the two magnetic compression experiments was obtained. The additional panels on Z1489 contained samples of PBX9501 and HMX crystals of varied orientations.

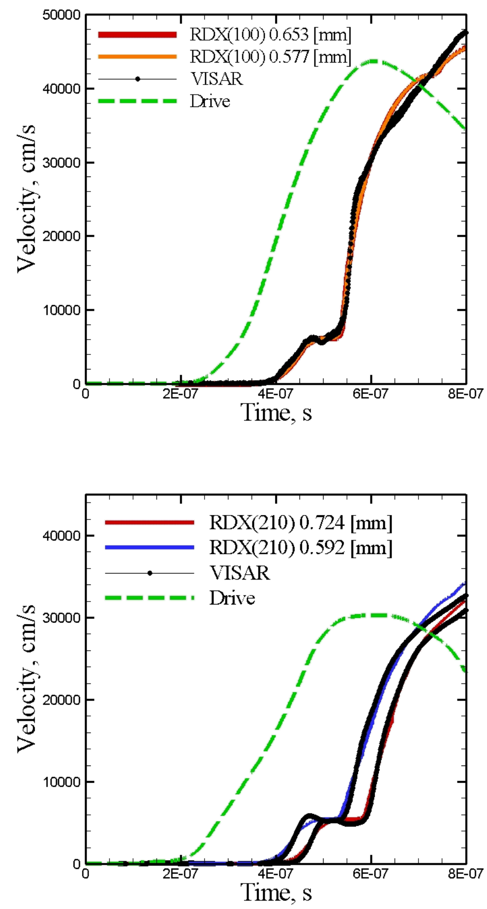

FIGURE 4. Particle velocity profiles in RDX (100) crystal using small pulser (top) and RDX(210) for Z (bottom).

This EOS for the RDX crystals were optimized separately for the small pulser and Z tests whereby a quadratic Mie-Grüneisen EOS with a elasticperfectly plastic strength model is assumed. A comparison of the VISAR data to the optimized EOS is shown in Figure 4. For the small pulser loading onto RDX(100) crystals ($\rho = 1.806$ g/cc and $\Gamma_0 = 1.29$) the optimization produced $c_0 = 2.47$ [mm/μs], $s_1 = 2.47$, $s_2 = -0.496$ with strength parameters: $Y = 5.68$ Kbar and $\nu = 0.135$. Applying the optimization to the Z loading for RDX(210) crystals produced $c_0 = 2.17$ [mm/μs], $s_1 = 2.78$, $s_2 = -0.505$ with strength parameters: $Y = 4.39$ Kbar and $\nu = 0.181$. The differences in the parameters are due to crystal orientation and well defined elastic-plastic transition is clearly seen similar to that observed in crystal HMX [3].

In the Z1289, one panel contained 4 samples of PBX9502 with varied thickness and the optimization procedure was applied assuming a M-G EOS (Equation 1). All four samples were used in the optimization including those that indicated shock formation. The resulting parameterization for PBX9502 ($\rho = 1.887 g/cc$) yielded $c_0 = 1.86$ [mm/μs], $s_1 = 3.16, s_2 = -1.75$, No strength effects were included in the analysis.

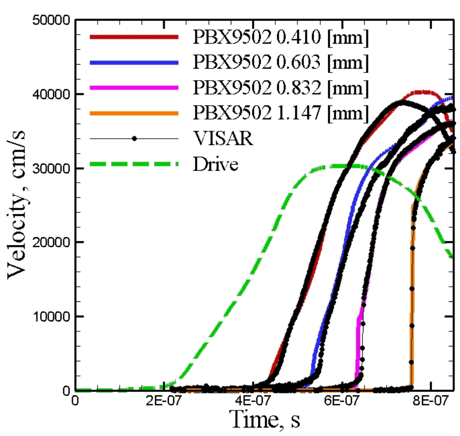

FIGURE 5. Particle velocity profiles in varied thickness of PBX9502 measured at the interface of a LiF (100) window.

CONCLUSION

In this study, isentropic ramp loading has been applied to a series of ICE configurations containing constituents of energetic composites. Ramp loading conditions were purposely designed to minimize the effects of reaction and material response data for equation of state and strength effects have been determined using a procedure incorporating forward analysis and optimization methods. Parameter sensitivity analysis has also been applied to determine the effects of experimental errors in the parameterization of assumed models. Although a variety of explosive crystals, binders, metal additives and composites have been studied only a few of these materials have been discussed here and additional details of these studies will be provided in a future publication.

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