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(U) Shock and Release Response of Unreacted Epon 828: Shot 2s-905

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This document summarizes the shock and release response of Epon 828 measured in the dynamic impact experiment 2s-905. Experimentally, a thin Kel-F impactor backed by a low impedance foam impacted an Epon 828 target with embedded electromagnetic gauges. Computationally, a one dimensional simulation of the impact event was performed, and tracer particles were located at the corresponding electromagnetic gauge locations. The experimental configuration was such that the Epon 828 target was initially shocked, and then allowed to release from the high-pressure state. Comparisons of the experimental gauge and computational tracer data were made to assess the performance of equation of state (EOS) 7603, a SESAME EOS for Epon 828, on and off the principal shock Hugoniot. Results indicate that while EOS 7603 can capture the Hugoniot response to better that 1%, while the sound speeds at pressure are under-predicted by ∼6 - 7%.

I. INTRODUCTION

Epoxy is used in the aerospace, manufacturing, and munitions industries, and as a result its high-pressure response must be well understood. Previous dynamic high-pressure research has been conducted on epoxy by Marsh[1] and Olinger[2], where in these cases the specific material studied is thought to be a Jeffamine-cured Epon 828 epoxy.[3] However these previous investigations focused solely on the initial shock Hugoniot response, and did not characterize its release from the high-pressure state. The present investigation summarizes results from a shock and release experiment conducted on unreacted Epon 828, and compares experimental results to those obtained from corresponding one dimensional calculations. Properties of the Hugoniot and release states are investigated specifically.

II. EXPERIMENTAL

To investigate the Hugoniot and sound speed at pressure response of Epon 828 an experiment was conducted on the 50 mm bore diameter LANL two-staged gas gun.[4] In this experiment a Kel-F impactor backed by a glass micro-balloon (GMB) foam was accelerated towards the Epoxy target at 3.319 km/s. A schematic of the experiment is given in Fig. 1, and initial conditions for the impactor and target materials are given in Table I. The shocked state in the Epoxy was recorded with electromagnetic gauges at different thickness locations within the target. Specifically, gauges were located at thicknesses of 0.00 (stirrup gauge), 1.28, 2.06, 2.85, 3.64, 4.42, 5.21, 6.00, 6.79, and 7.57 mm (remaining gauges are tracker gauges). The gauges measure the material velocity u_P directly, and the shock velocity U_S is calculated using data from tracker gauges 1 and 2, and the arrival of the shock at successive gauge locations for gauges up to 3.64 mm into the target. With the impact velocity known, impedence matching is used with the measured U_S and u_P to calculate the remainder of the Hugoniot state.[5] The Lagrangian sound speed C_L was calculated from the experiment using the original position of the gauges and the temporal arrival of the initial rarefaction, i.e. the point at which u_P begins to decrease in the gauge data. The Eularian (bulk) sound speed C is calculated using the relation:

$$C = C_L \left(\frac{\rho_0}{\rho} \right) . \quad (1)$$

Results obtained from the experiment for the Hugoniot state and the sound speeds at pressure are given in Table II.

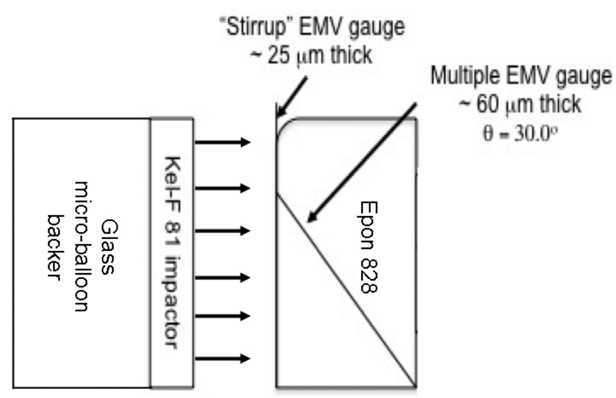

FIG. 1. Experimental design for shot 2s-905. Dimensions not to scale.

III. COMPUTATIONAL

The experiment was also modeled in one dimension using the LANL hydrocode FLAG.[6] Calculations were

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TABLE I. Initial conditions for impactor and target materials. Densities marked with * are geometric.

Material	Density (g/cm^3)	Thickness (mm)
GMB	0.533*	5.815
Kel-F	2.148*	0.978
Epon 828	1.148	22.990

TABLE II. Comparison of Experimental (Exp.) and Computational (Comp.) data. Uncertainties in experimental data were only reported for $U_S = \pm 0.039$ km/s and $u_P = \pm 0.020$ km/s. Calculated uncertainties for sound velocities were $C_L = \pm 0.15$ km/s and $C = \pm 0.10$ km/s.

	U_S (km/s)	u_P (km/s)	P (GPa)	ρ (g/cm^3)	C_L (km/s)	C (km/s)
Exp.	5.632	1.932	12.50	1.747	10.36	6.81
Comp.	5.603	1.952	12.56	1.762	9.73	6.34

performed with a constant mesh size of 5μm, with dimensions matched to experiments. The GMB material was modeled as fused quartz, EOS 7387, at an initial porous density of 0.533 g/cm^3. To bring the GMB from its initial porous state to a state on the EOS a single stage ramp model was used with the characteristic slope parameter 'a' = 0.000003 Mbar. The Kel-F impactor was modeled with a Grüneisen EOS fit to available shock data from Marsh[1] at an initial density of $\rho_0 = 2.140$ g/cm^3. The Epon 828 was modeled using EOS 7603[7] at an initial density of $\rho_0 = 1.148$ g/cm^3 with 'a' = 0.00001 Mbar. All materials were treated as having no strength. Tracers were located within the Epon 828 at the impact surface, and at distances corresponding to the experimental gauge locations. The calculated pressure P, density ρ, and material velocity u_P states in the simulations were pulled directly from the tracer data, and were used to calculate the shock velocity U_S via the Rankine-Hugoniot jump conditions. The Lagrangian sound velocity was calculated using the rarefaction arrival times and original gauge locations for the first four tracker gauges. The Eularian sound speed was calculated using Eq. 1. Results from the one dimensional calculations are given alongside those from experiment in Table II and graphically for the first four tracker gauges in Fig. 2.

IV. COMPARISION

A comparison of the calculated response based on EOS 7603 and that measured in the experiment it provided here in terms of the Hugoniot state and the release behavior. Inspection of the Hugoniot states given in Table II reveals that agreement between the experiment and calculation is quite good. For the measured quantities U_S and u_P, the results obtained from the calculation are within the experimental uncertainty limits; however, the values are consistently below those reported in the experiment. Figure 2 illustrates this agreement further, where shock breakout times coincide for all tracker gauges shown, and the steady state material velocity profiles (with the exception of the leading visco-plastic and trailing rarefaction arrival affects in the experimental data) also coincide for the first three tracker gauges. Further, the calculated values for both P and ρ match those from experiment to better than 1%.

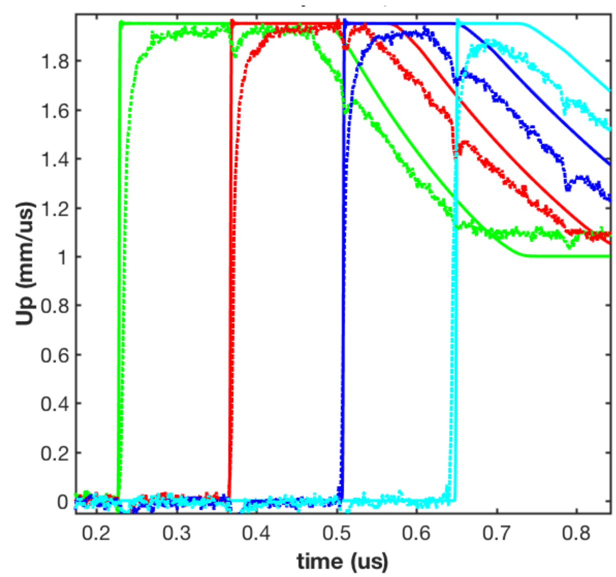

FIG. 2. Comparison of experimental (dotted) and calculated (solid) material velocity wave profiles for tracker gauges at 1.28, 2.06, 2.85, and 3.64 mm from impact surface for shot 2s-905.

The sound speeds at pressure show less agreement than the Hugoniot response. Table II gives calculated values for C_L and C that are approximately 6% and 7% lower than the experimental values, respectively. The reported uncertainties for the calculated values in Table II indicate that these uncertainties are not large enough to encompass the experimental data. Comparing the release portion of the wave profiles given in Fig. 2 shows that release occurs later in time for the calculated response. This results in overtake of the steady state material velocity not occurring until the sixth tracker gauge (5.21 mm) in the calculation (not shown in Fig. 2). This behavior is observed to occur experimentally at the fourth tracker gauge (3.64 mm).

V. CONCLUSIONS

The Hugoniot and release response of unreacted Epon 828 was tested experimentally using an embedded gauge technique. The dynamic impact experiment was modeled in one dimension using the LANL hydrocode FLAG, with the material response of Epon 828 captured using the SESAME EOS 7603. Comparison of the calculated and experimental responses indicate that EOS 7603 performs well at capturing the Hugoniot state, to $< 1\%$ accuracy. However, EOS 7603 under-predicts the sound speeds at pressure by $\sim$6 - 7%. Additional experiments that probe the release response of unreacted Epon 828 are recommended, to determine if sound speeds are consistently lower than experiment at other pressures. If so, modification of the unreacted EOS for Epon 828 should be undertaken to include the appropriate behavior for the sound speed at pressure.

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