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PROTON RADIOGRAPHY OF PBX 9502 DETONATION SHOCK DYNAMICS CONFINEMENT SANDWICH TEST[1]

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Abstract. Recent results utilizing proton radiography (P-Rad) during the detonation of the high explosive PBX 9502 are presented. Specifically, the effects of confinement of the detonation are examined in the LANL detonation confinement sandwich geometry. The resulting detonation velocity and detonation shock shape are measured. In addition, proton radiography allows one to image the reflected shocks through the detonation products. Comparisons are made with detonation shock dynamics (DSD) and the reactive flow model Ignition and Growth (I&G) for the lead detonation shock and detonation velocity. In addition, predictions of reflected shocks are made with the reactive flow model.

Keywords: detonation: shock dynamics, PBX 9502
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INTRODUCTION

We wish to examine the effect confinement plays in the propagation of detonation shock waves within a high explosive (HE). The hydrodynamic interaction of this effect can be understood by examining the pressure/streamline-deflection matching condition at the HE/inert interface. Although a full hydrodynamic simulation of the complete flow is needed for a detailed description of this interaction, a relatively simple shock polar analysis provides a good leading-order prediction of the confinement effect. The shock polar analysis considers matching the flow states (pressure and streamline deflection) that are found immediately behind the lead shocks. This is done in a reference frame that moves with the detonation shock-inert interface intersection. To carry out the analysis, the equation of state (EOS) of the unreacted HE and inert are required, as well as an assumed value for the detonation phase speed. We are interested in the effect confinement has on the detonation front in the region of the reaction zone. Preliminary experiments and the equations used for this analysis stem from the shock conditions of the Euler equations, and have been given in [1]. Further theoretical and computational analysis can be found in [3] and [4]. Here, results are presented for a single experimental "sandwich" test, involving the confinement of the high explosive PBX 9502 (95% TATB, 5% Kel-F binder) by polymethylmethacrylate (PMMA).

EXPERIMENTAL SETUP

The original design of the detonation confinement test can be found in [2]. For use with proton radiography, the design had to be significantly modified, to eliminate the metal surrounding the short dimension of the explosive. This metal would have caused an obstructed view of the HE for the radiography. A redesigned setup, involving anvil "clamps" can be seen in Figure 1. The initiation system is identical to the earlier experiments, namely a detonator initiates a line wave generator, then an 8 mm-square×5.950 inch long CompB booster which finally lights the 8 mm×5 inch×6 inch PBX 9502 charge.

This particular experiment had the sample of PBX

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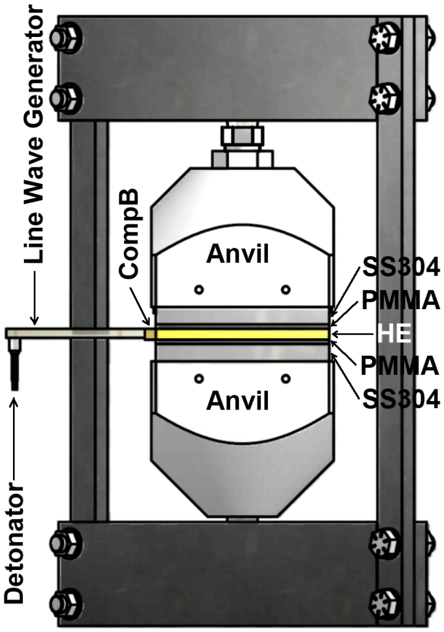

FIGURE 1. Schematic of the P-Rad Sandwich Test.

9502 sandwiched symmetrically by 4.37 mm of PMMA and then stainless steel 304 (SS304). As in the original system, pins were used to measure the phase velocity of the detonation wave. Computational experiments, such as [4], suggest that a Mach reflection occurs in the PMMA, as the lead shock reflects off of the SS304. Since the Mach reflection takes a substantial period of time to develop steadiness, it was decided to place the pins embedded in the PMMA, so as to have a 1 mm stand-off from the PMMA/PBX 9502 interface. There were a total of eleven pins, spaced 10 mm apart, over the last ~80% of run.

COMPUTATIONAL RESULTS - I&G AND DSD

All computations were performed using an adaptive mesh refinement strategy [5] to deal with the multi-scale nature of detonation propagation. We utilize a level set technique, specifically the Ghost Fluid Method (GFM) [6], to treat the multi-material interfaces. The GFM allows for discrete jumps in the density, transverse velocity, reaction progress and EOSs across material interfaces. The GFM was extended to handle an arbitrary number of materials. The underlying flow solver is a 3rd order Convex Essentially Non-Oscillatory (CENO) spatial scheme with 3rd order total variation diminishing Runge-Kutta time integration. Formally, for smooth flows, the underlying scheme is fully 3rd order accurate in space and time. For solutions containing captured shocks and material interfaces, only 1st order convergence is expected.

TABLE 1. Mie-Gruneisen inert material parameters for $U_S = c_0 + sU_P$ and $\rho_0\Gamma_0 = \rho\Gamma$.

material	ρ_0-g/mm^3	c_0−mm/μs	s	Γ_0
PMMA	1.186	3.061	1.311	1.5
SS304	7.926	4.480	1.51	2.18

The I&G shock initiation model [8] was used to describe the reactive flow in PBX 9502. Note that there are several different parameter sets in the literature. Parameters [8] were chosen since the focus was on detonation propagation (not dead zones or initiation, which generally have higher state sensitivity) and interaction with inert confinement. This model is fully described in a later work [9]. It is noted that the rate law has 3 components, which model the ignition stage, growth stage and burn-out stage of detonation (with each stage generally proceeding an order of magnitude slower than the previous stage). The inert EOS parameters are given in Table 1.

Solutions were computed at 4 different resolutions, Δx =1/9, 1/18, 1/36 and 1/72 mm to gauge the effect numerical resolution has on the resulting solution. See Table 2 for resulting detonation velocities as a function of resolution. Note that even for a very fine resolution (~14 micron grid spacing), the observed detonation velocity is still changing by tens of meters per second. Given the complex structure of the rate modeling [4] [9], it is not surprising that the solution is still quite sensitive at these fine grids.

The DSD results from [1] predicted a steady traveling detonation velocity of 7.474 mm/μs. See [1] for complete details of model parameters, and predicted results. Note that DSD, by itself, does not predict reflected shocks in products, etc., but would need to be incorporated into a hydrodynamics code to examine reflected waves.

P-RAD RESULTS AND DISCUSSION

Of the eleven pins used in the experimental setup, only five triggered properly; see Table 3. The result-

TABLE 2. Average detonation velocity versus Δx for numerical simulations.

Δx–mm	D_0–mm/μs
1/9	7.2553
1/18	7.2903
1/36	7.3518
1/72	7.3749

TABLE 3. $x-t$ pin data; best fit yields $D_0 = 7.467 \pm 0.029$ mm/μs

x–mm	$t-\mu$s
10.000	25.604
20.000	26.952
40.000	29.653
50.000	30.987
60.000	32.285

ing measured detonation velocity was $D_0 = 7.467 \pm 0.029$ mm/μs, via linear regression. The 29 m/s uncertainty in the detonation velocity is higher than typical for LANL, and was mostly due to several of the pins not triggering (in Table 3 the spacings in x are relative to the first pin. Pins at 0, 30, 70, 80, 90 and 100 mm did not trigger properly). None-the-less, the standard error is still less than 1/2% of the detonation velocity.

These results indicate that the pin placement, i.e. how close the pins are to the HE/inert interface, is an important issue when attempting to measure very accurate detonation velocities (on the order of 1/10% error in detonation velocity). Of note, the detonation velocity for the original test [2], with PMMA confinement, indicated $D_0 = 7.519 \pm 0.007$ mm/μs, which is significantly higher than observed here. The difference between the tests is that the original pins were placed on the outside of the PMMA, and the formation of the Mach reflection causes an apparent increase in phase speed over the pins placed nearer to the HE/inert interface. Given enough run length, this issue would go away (eventually the Mach reflection becomes steady), but for the finite run length investigated here, it appears there is an increase of $\sim$50 m/s, if one places the pins outside of the Mach reflection area.

Figure 2 shows the comparison of the I&G model with the P-Rad results, with the axis of symmetry being the demarcation between them. The Mach reflection can be seen in both the radiograph and simulation results. In the top frame of Fig 2, at early times, a regular reflection is observed, whereas later (lower frames) a Mach stem is observed. Also, various reflected shocks are observed in both the radiograph and simulation.

In conclusion, the DSD model does a good job of predicting the detonation speed and lead detonation shock shape, while I&G provides a reasonable prediction of detonation velocity and reflected shocks, albeit at a significantly higher computational cost.

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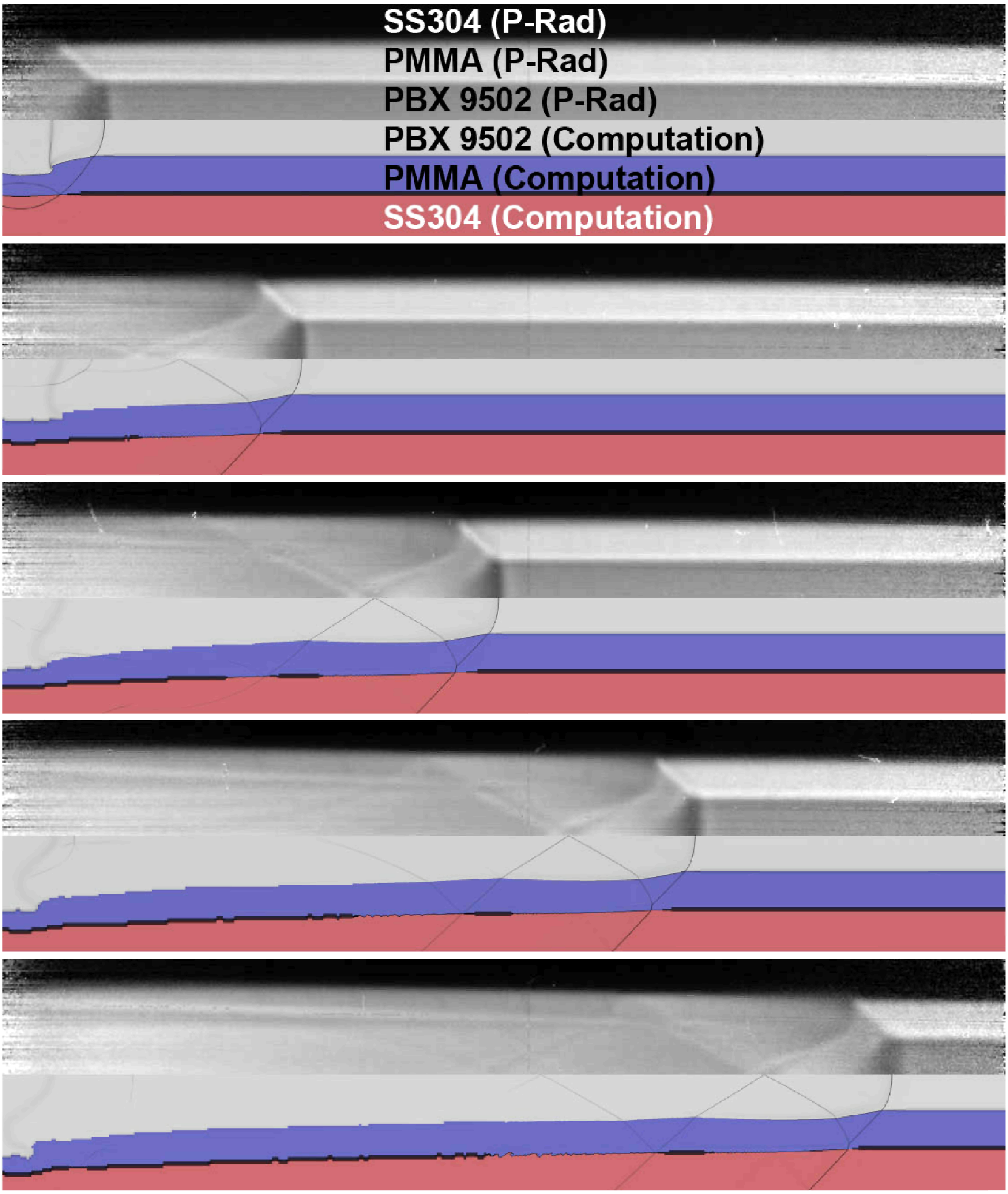

FIGURE 2. Comparison of P-Rad experimental results and numerical simulation at 3 μs intervals, $\Delta x = 1/36$ mm.