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TITLE **PRESHOCK DESENSITIZATION OF HIGH EXPLOSIVES MONITORED WITH IN-MATERIAL MAGNETIC GAUGING**

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PRESHOCK DESENSITIZATION OF PBX EXPLOSIVES*

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Preshocking delays initiation of PBX-9404 and PBX-9501, relative to unshocked material. In PBX-9404 preshock experiments, a first shock of 2.3 GPa was followed 0.65 µs later by a second shock of 5.6 GPa. In PBX-9501, a preshock of 2.8 GPa and 0.32 us duration was followed by an initiating shock of 6.0 GPa. Both PBX explosives show clear desensitization while the preshock persists. In PBX-9404, initiation of detonation occurs nearly as anticipated for the material, after coalescence of the preshock and main shock into a single wave. Multiple embedded magnetic gauges were used to measure the shock histories. Our data indicates a slightly longer run to detonation than expected, even though a single wave is initiating the material. A slight stress reduction at coalescence, as required by the shock dynamics, may be responsible for the overrun. A reactive wave is clearly evident while the preshock persists. The long run to detonation indicates that this reactive wave is not driving the initiation. A set of four preshock experiments were performed on PBX-9502, which is unreactive at these pressures, to investigate the shock dynamics of the two waves in the HE.

INTRODUCTION

Preshocking resulting in delayed initiation has been examined in PBX-9404 and PBX-9501, using multiple magnetic gauges embedded in the initiating explosive. These measurements of particle velocity enable us to follow the evolution of the reactive wave behind the shocks, and to observe the development of this wave into a detonation. Our observations address the previous idea that the material is completely desensitized while the preshock is active, but that the normal run-to-detonation (as given by the pop plot) for the material applies as soon as the two shocks coalesce into a single shock.

Previous work on preshock desensitization was done by Campbell and Travis.[1] In their experiments, a detonation wave was run into a preshocked region, where it was weakened and eventually extinguished. The run distance was given by $P^{2.2}\ \tau = 1140$ (kbar and µs), for both PBX-9404 and Comp B. The active region was interpreted as an induction time for hot spot deactivation in the material.

EXPERIMENTAL SETUP

Our experiments are performed using a light gas gun to generate well supported, planar shock waves of well-known pressure. The experiments are one-dimensional over the region and time of interest. The square pressure pulse generated by the projectile may eliminate some variables to simplify consideration of the time-dependent behavior of the growth of the reactive wave, and allows accurate manipulation of time and pressure parameters. The gas gun can reach projectile velocities of up to 1.4 mm/µs, corresponding to pressures to about 10.5 GPa in PBX materials when single crystal sapphire impactors are used. This pressure will detonate PBX-9404 and PBX-9501, but is not sufficient to promote prompt reaction in PBX-9502.

Embedded multiple magnetic gauges provide unique measurements, in the Lagrangian frame, of the time evolution of the shocks, for up to 3 µs. The gauge package consists of either 5 nested particle velocity gauges and 5 impulse gauges, or of 10 particle velocity gauges, to take data at 1/2 mm depth intervals when the gauges are placed at a 30° angle. Use of multiple gauges gives independent measurements of particle velocity (u_p) and shock velocity (U_s). These parameters are obtained directly from the data.

Preshock experiments are done using a composite projectile mounted impactor consisting of a low impedance thin layer on the front surface of a high impedance backing material. The projectile

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impacts a precisely machined flat explosive cylinder, into which the gauge package is glued at a 30° angle. The experimental setup and x-t diagram for a PBX-9502 experiment are shown in Fig. 1.

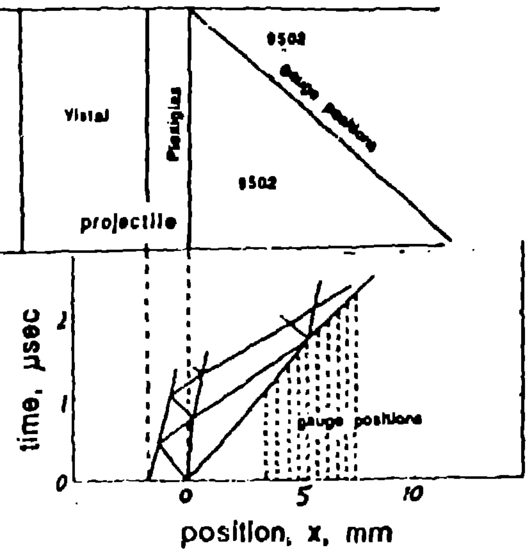

Figure 1. Experimental arrangement and x-t diagram showing preshock and main shock generation for a PBX-9502 experiment.

Experiments have been done on PBX-9404, PBX-9501, and PBX-9502. Data obtained from a shot on PBX-9502 are shown in Figure 2. The character of the input waves and time of coalescence are clearly evident, since the material behaves as an inert material at these pressures. Data from a pair of shots done on PBX-9404 is superimposed in Figure 3. Preshock and main shock pressures of 2.3 and 5.6 GPa and wave separation of 0.7 μs are accurately reproduced between the two shots. Growth of the reactive wave to near detonation is evident in Figure 3. The reactive wave emerging during the preshock is more clearly presented in Figure 4, in which maximum particle velocity vs location serves to show the approximate position of the reactive wave.

Detonation occurs after 9.4 mm of run, from impact of the first shock, or 8.7 mm after the second shock enters the explosive. The pop plot for PBX-9404 predicts[2] a run of 3.5 mm at the pressure of the second shock (5.6 GPa). Measured from the location of wave coalescence the run is 3.8 mm, slightly longer than the run predicted from the Pop plot. The slight overrun is also observed by John Ramsay in plane wave lens experiments.[3]

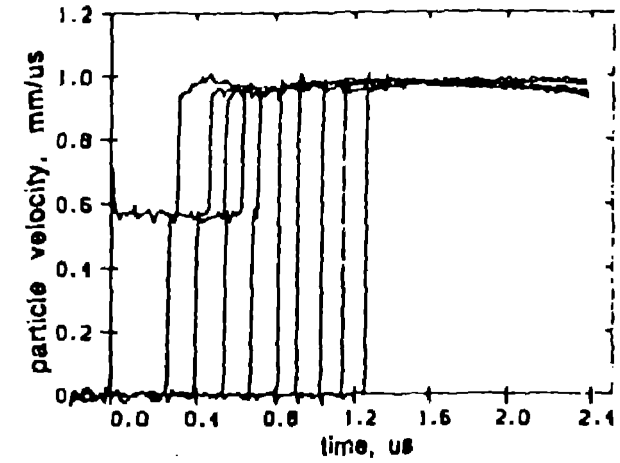

Figure 2. Data from experiment on PBX-9502 with P_1 = 3.71 GPa, t_1 = 0.32 μs, and P_2 = 8.19 GPa.

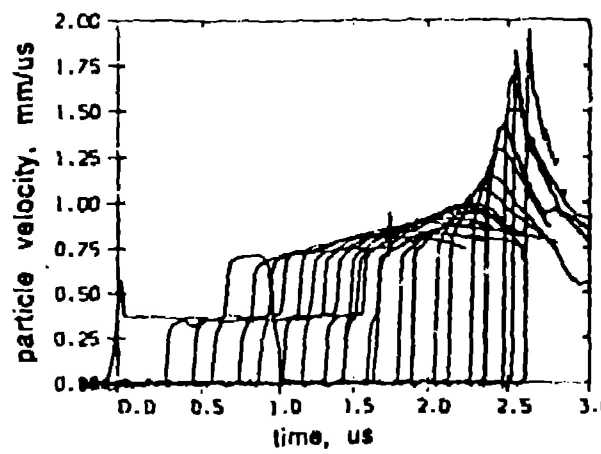

Figure 3. Data from two experiments on PBX-9404, showing growth of reactive wave in preshocked material: P_1 = 2.3 GPa, t_1 = 0.68 μs, P_2 = 5.6 GPa.

DISCUSSION

The Hugoniot crossing diagram in the t-x plane is shown in Figure 5. The MACRAME code[4] was used to generate this diagram. At wave coalescence, the return to a single shock in the material requires a switch from the second to the principal Hugoniot, with corresponding generation of a small rarefaction in the material. The magnitude of this pressure drop is calculated, using the MACRAME code, to be at most 0.15 GPa (2.7%) in PBX-9502, and about 0.06 GPa (1.1%) in PBX-9404, if the PBX-9404 were inert. While the magnitude of this drop is not sufficient to alter the run obtained from the Pop plot appreciably, it may

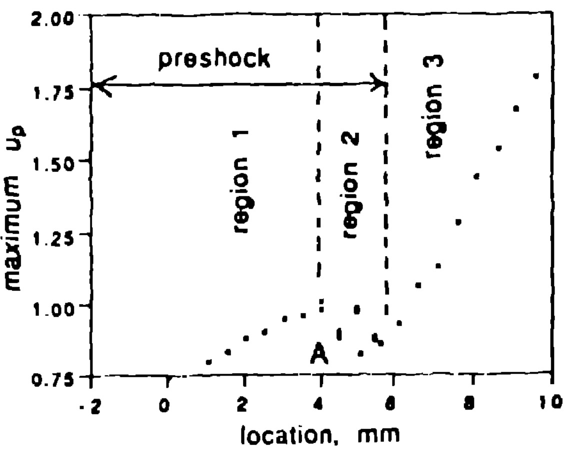

Figure 4. Maximum particle velocities of reactive waves in PBX-9404 experiments. Collision of reactive wave and small rarefaction occurs at point A.

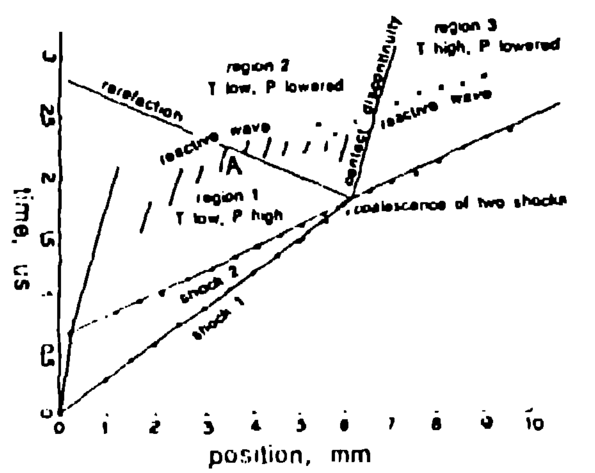

Figure 5. Complete x-t diagram for experiment on PBX-9404 showing reactive waves (from experimental data) and rarefaction.

lengthen the run by a small amount, within the margin of error of the Pop plot.

The bulk temperature of the material is lowered substantially in the doubly shocked case at a given pressure, by up to 25% at 4 GPa. A contact discontinuity separates the cold region behind the two shocks from the hot single shock region, as shown in Figure 5.

The PBX-9502 data is expected to exhibit this pressure drop as a propagating perturbation on the flat region of the second wave. Careful examination of the record in the region where the rarefaction wave is calculated to be (velocity obtained from MACRAME calculation) reveals no perturbation on the flat top of the wave. The 1.7% rise calculated in u_p was expected to be large enough to detect, but this is apparently not the case. The uncertainty in particle velocity in these records is about 1 to 2%.

The PBX-9404 experiments exhibit the same particle velocity profiles as those observed for PBX-9502, with the addition of the reactive wave emerging after the second shock. This wave emerges almost as soon as the second shock pressure is established in the material, contradicting the idea that the material has been completely desensitized by the first shock. According to Campbell and Travis' criterion,[1] the first shock is too short to produce desensitization, with $P_1^{2.2}\tau = 644 < 1140$.

However, the emergence of the reactive wave before coalescence apparently does not contribute to the development of the detonation once coalescence of the two waves has occurred. The run is, instead, extended slightly after establishment of a single shock.

The small rarefaction discussed earlier propagates back into the reacting material as shown in Figure 5. When the reactive wave encounters the rarefaction, a reduction in the maximum u_p reached by the wave occurs, as shown in Figure 4. The reactive wave is quenched at the point (marked "A") at which the rarefaction meets it. This drop is seen in individual waves as an early maximum in u_p and then a sharp drop off, a truncation of the reactive profile.

These observations lead to a model in which the preshock compresses the material, and then the second shock promotes a reaction. The second shock is propagating in a preshocked region of elevated T, P, and density. This second shock produces a state, off the principal Hugoniot, of lower temperature for the given final pressure. Thus the reactive wave propagates in a region of relatively low T, high P, and high density, which has been precompressed to a density around 2.08 g/cm^3, a density at which the run to detonation might be expected to be exceedingly long based on estimates made in Ref. 6. The elevated initial density in this region also is associated with the removal of some fraction of the hot spots in this material. This region is shown on the x-t diagram, Figure 5, as region 1, bounded by the input shock and the returning small rarefaction. Under these conditions, the reactive wave accelerates slowly,

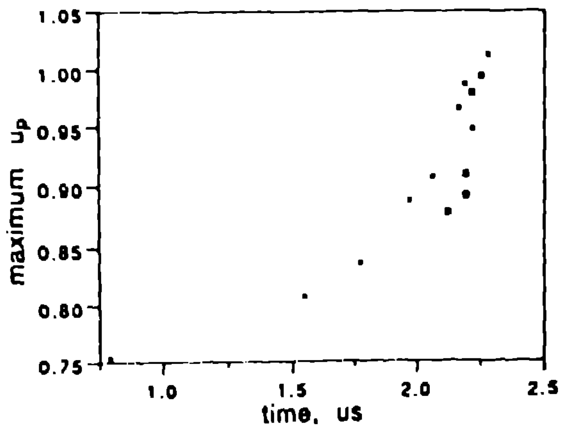

Figure 6. Maximum particle velocities of reactive waves in PBX-9404 experiments, in region of preshock. Heavy points are maxima of waves arising after collision with rarefaction, in region 2.

propagating at nearly the same velocity as the second shock which promotes it.

Encountering the rarefaction, the reactive wave is attenuated. The wave proceeds in a second region (Figure 5 region 2) in which P and density are lowered slightly, and T is maintained at its relatively low value. The initial conditions are still dictated by the preshock. The reactive wave in this region exhibits a reduced particle velocity and also a wave velocity near zero, as shown in Figures 5 and 6.

The establishment of a single shock generates a contact discontinuity, which bounds a third region (Figure 5 region 3). Across this contact discontinuity, the T state is raised to that prescribed by the principal Hugoniot. The single shock propagates into material with initial T and density again in the usual (1.84 g/cm^3, 230 K) range for development of a normal heterogeneous reactive wave. Neither Figure 4 nor Figure 5 indicates that the reactive wave in this region is unrelated to the reactive waves in the preshocked regions, but the long run to detonation supports this idea. This wave develops into detonation as expected. The run to detonation is extended slightly over that anticipated at the pressure of the second wave because of the slight pressure reduction at coalescence.

The $P_1^{2.2}\tau > 1140$ criterion[1] for desensitization may arise partly from the condition where the longer τ allows the reaction in region 1 to run nearer completion, chemically changing the remaining hot spots, either overpressuring them with reaction product gases or altering the local chemistry through partial reaction. We anticipate doing experiments in this regime.

CONCLUSIONS

A pressure drop is required by the shock dynamics of a double shock coalescing to a single shock. This pressure drop is not visible in PBX 9502 records, but may nonetheless be resulting in the extended run observed in PBX-9404 after coalescence of the two shocks.

A reactive wave is emerging in the preshocked material, but apparently does not contribute to the detonation, as indicated by an extended rather than truncated run after coalescence. The reactive wave is depleted by the small rarefaction at coalescence. The reactive wave in the preshocked region may indicate chemistry or "pre-burning" of the hotspots, as well as their compression, as a mechanism for desensitization.

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