Title: SHOCK INITIATION OF NEW AND AGED PBX 9501 MEASURED WITH EMBEDDED ELECTROMAGNETIC PARTICLE VELOCITY GAUGES

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Shock Initiation of New and Aged PBX 9501 Measured with Embedded Electromagnetic Particle Velocity Gauges

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ABSTRACT

We have used an embedded electromagnetic particle velocity gauge technique to measure the shock initiation behavior in PBX 9501 explosive. Up to twelve separate particle velocity wave profile measurements have been made at different depths in a single experiment. These detail the growth from an input shock to a detonation. In addition, another gauge element called a “shock tracker” has been used to monitor the progress of the shock front as a function of time and position as it moves through the explosive sample. This provides data similar to that obtained in a traditional explosively driven wedge test and is used to determine the position and time that the wave attains detonation. Run distance-to-detonation vs. input pressure (Pop–plot) data and particle velocity wave profile data have been obtained on new PBX 9501 pressed to densities of 1.826, 1.830, and 1.837 g/cm$^3$. In addition, the same measurements were performed on aged material recovered from dismantled W76 and W78 weapons. The input pressure range covered was 3.0 to 5.2 GPa. All results to date show shock sensitivity to be a function only of the initial density (differences in density as small as 0.005 g/cm$^3$ produce measurable changes in sensitivity) and not of age.

INTRODUCTION

The current report is a condensation of our report of Reference 1. Due to space limitations, we cannot fully reference the current paper, but complete references can be found in this reference.

Recent interest in the characteristics and shock initiation of PBX 9501 has come from two fronts. First, the problem of accidental mechanical insult producing a violent reaction has prompted studies in the low stress regime by Jerry Dick using planar impacts, and by Deanne Idar, and Steve Chidester using spherical impactors. Secondly, it has become advisable (necessary) to leave the nuclear weapons (of which PBX 9501 is a component) in the stockpile for much longer periods than was originally envisioned; thus, the need to know if the properties of PBX 9501 change over long periods of time. Since there was not a large amount of baseline information on shock initiation of PBX 9501, comparisons between new and aged material were impossible. This study resulted from the need for this data.

The remainder of this report details our study of the sustained shock initiation of PBX 9501. To obtain baseline data we studied samples made from one powder lot and pressed to three different densities. These results were compared with data obtained from material recovered from two different weapons that had been in the stockpile for 124 and 201 months, respectively. Complete details and further references are available in Ref 1.

EXPERIMENTAL DETAILS

PBX 9501 Samples

Three different “new” PBX 9501 sample materials were made at Los Alamos National Laboratory (LANL), and two sample materials were recovered from dismantled weapons. These are summarized in Table 1. Densities were measured by Jose Archuleta of DX-2. All new sample materials were pressed (using the methods given in Table 1) from Holston PBX 9501 molding
Table 1. Summary of Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Powder Lot</th>
<th>Piece No.</th>
<th>Pressing Method*</th>
<th>Density (g/cm³)</th>
<th>Age (months in stockpile)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>730-010</td>
<td>96-741319</td>
<td>Hydrostatic</td>
<td>1.826 ± 0.001</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>730-010</td>
<td>97-525099</td>
<td>Hydrostatic</td>
<td>1.830 ± 0.001</td>
<td>0</td>
</tr>
<tr>
<td>C</td>
<td>730-010</td>
<td>97-264309x</td>
<td>Ram</td>
<td>1.837 ± 0.001</td>
<td>0</td>
</tr>
<tr>
<td>W76</td>
<td>730-006</td>
<td>76-1100830</td>
<td>Hydro/Mandrel</td>
<td>1.838 ± 0.001</td>
<td>124</td>
</tr>
<tr>
<td>W78</td>
<td>685-006</td>
<td>78-1020331</td>
<td>Hydro/Mandrel</td>
<td>1.838 ± 0.001</td>
<td>201</td>
</tr>
</tbody>
</table>

* All pressings were made at 100°C.

powder lot 89C730-010 which was manufactured in 1989. We designate the new materials A, B, and C.

**Overall Experimental Configuration**

The overall configuration for the initiation experiments is shown in Figure 1. This is the same configuration developed by Vorthman, and used in many earlier LANL studies. A projectile made with a Lexan front, is faced with a non-metallic impactor disk and launched in a 72-mm bore single-stage gas gun. When the impactor strikes the explosive sample, a planar shock wave is generated which begins the initiation process. Gauges embedded in the sample at various depths from the impact plane measure the particle velocity, as well as the position of the shock front with time. The workings of these gauges are detailed in Ref. 1, but typical results will be shown in the following section.

The projectile impact velocity and the choice of impactor material determine pressure input to the sample. With gas guns, the impact velocity, and thus the input pressure, can be precisely controlled and measured. Impactors used for the present experiments were either of Vistal (a high-density aluminum oxide ceramic sold by Coors), z-cut alpha quartz, or z-cut sapphire. Impact velocities of 0.55–0.82 km/s produced stresses of 3.1–5.2 GPa in the PBX 9501 samples.

**EXPERIMENTAL RESULTS AND DISCUSSION**

**Basic Results**

Basic results for a single embedded gauge shock initiation experiment are shown in Figures 2 and 3. Figure 2 shows a 3-D plot of the particle velocity versus time at each of the 11 gauge positions, which range in depth from 0 to 5 mm into the explosive. In this experiment, PBX 9501 of type A (see Table 1) was impacted with a Vistal impactor at a velocity of 0.817 km/s, producing an input of 5.12 GPa. The individual wave profiles from different gauges are given different colors for ease of reading. The input particle velocity is about 0.7 km/s and this evolves to over 2 km/s, a full detonation, by the time the wave reaches the last gauge located at 5 mm into the sample.

![Figure 1. Overall experimental configuration. Explosive sample installed in gun target chamber and magnetic field.](image-url)
Figure 2. Particle velocity wave profiles in PBX 9501 for a 5.15 GPa input.

The input wave is flat–topped early on, as shown by the first wave profile. The other wave profiles show some increase in amplitude at the shock front and a large following wave which builds with depth and eventually overtakes the shock front. This behavior indicates a delay in release of hot-spot energy. At about the time the wave has reached the last gauge, the following wave has overtaken the shock front and a full detonation has been achieved.

The x-t plot showing the position of the shock front with time for the same experiment is shown in Figure 3. Red and black points were obtained from a shock tracker gauge. Green points were obtained from the wave arrival times and initial gauge positions of the particle velocity gauges shown in Figure 2. The black points indicate times/positions where the explosive is fully detonating. These data are similar to what is obtained in traditional explosively driven, optically recorded wedge tests. Lines through the data indicate shock velocity (initial slope) and detonation velocity (final slope). A mathematical fitting method is used to determine the distance and time where detonation is achieved. (In summary, it determines the point where 99% of the final detonation velocity is achieved. The turnover point is roughly the place where the data points join the detonation line.)

Together, the wave profiles and the x-t trajectory of the position of the shock front with time provide excellent material for testing reactive burn models in hydrocodes.

**Effect of density on wave profiles**

Figure 4 shows the effect of initial density on the particle velocity wave profiles. Two experiments are shown in Figures 4a, and 4b. In each experiment a Vistal disk impacted the explosive sample at 0.665 km/s producing an input stress of 3.9 GPa. Both experiments had gauges located at 0 and 3 - 8 mm. Figure 4a shows wave profiles from a shot using the explosive with initial density 1.826 g/cm³ and Figure 4b shows wave profiles from a second shot using the explosive with initial density 1.830 g/cm³. There are clear differences between the two sets of data even with a density change of only 0.004 g/cm³.
Figure 4. Effect of density on wave profiles. Results shown are from two experiments on 2 samples. Both experiments had the same input stress of 3.9 GPa and the gauges located at about the same positions. Explosive material in (a) had 1.826 g/cm$^3$ density and that in (b) had 1.830 g/cm$^3$ density.

In the 1.826 g/cm$^3$ sample, detonation was achieved at 7.2 mm, near the second to last gauge. This is quite apparent in Figure 4a, as C-J particle velocity of 2.2 km/s is reached at the second to last gauge. In the 1.830 g/cm$^3$ sample, detonation was not achieved until 8.8 mm, well beyond the last gauge. The last wave profile is well below the C-J condition. These figures clearly show that small changes in initial density significantly affect the wave profiles in the buildup to detonation. As expected, higher density materials do not build to detonation as quickly as low-density materials.

Effect of age on wave profiles

Figure 5 shows the effect of sample age on the particle velocity wave profiles. Wave profiles are presented from three experiments using the same input stress of 5.22 GPa and the same sample density, but the age of the explosive varies. The red traces are from newly pressed material, the blue traces are from the W76 material that was aged 124 months in stockpile, and the green traces are from the W78 material that was aged 201 months in stockpile. Gauges were located at roughly, but not exactly, the same positions and spanned depths of 0 - 5 mm.

Wave profiles clearly show very good repeatability from one experiment to the next, i.e., corresponding profiles from all three experiments fall almost exactly on top of one another. The slight differences in wave arrival times are caused by slight differences in the depths of individual gauges. At the last gauge, where one would expect differences to be greatest, profiles from all three experiments are very nearly the same. Clearly, the age of the sample has almost no effect on the wave profiles and the shock initiation process.

Thus, the wave profiles show that density affects the shock initiation process but sample age does not.

Pop-plots

The Pop-plot (named after one of its originators, Alphonse Popolato) plots the run distance or time to detonation as a function of the input stress (pressure). Most commonly it is plotted as a Log-Log plot. It has been found to be a very useful tool for measuring and ranking the shock sensitivity of explosives.
Figure 6 presents Pop-plots for the 3 different density new PBX 9501 materials: A, B, and C. In this figure, we clearly see an increase in sensitivity with decreasing density. For a given input stress, run distances-to-detonation are shorter for lower density materials than those for higher density materials. Differences are most distinct at low pressures. This result parallels the differences in wave profiles for different density materials, which were seen in Figure 4. Those results also showed faster buildup to detonation for lower density materials. It is noteworthy that we have been able to measure sensitivity changes correlated to density differences as small as 0.005 g/cm³. This suggests that these kinds of experiments are a powerful discriminator for small changes in material parameters affecting initiability, which might take place in material formulation, pressing or aging.

Figure 7 presents Pop-plots for the two stockpile aged PBX 9501 materials; the 124 month old W76 material, and the 201 month old W78 material. These two materials had nominal densities of 1.838 g/cm³. For comparison, the run distances/times and the linear fit for the new 1.837 g/cm³ material (material C) is also shown. These data and their fit provide a baseline so that we can make comparisons and see if age significantly affects the run distance (time)-to-detonation.

While there is some scatter about the material C or baseline data fit, there is no definitive trend. All of the data from the aged explosives lie about as far from the baseline fit as do the baseline data. In addition, the error bars are such that the baseline fit goes through all the points (if error bars are included). The lack of difference in the Pop-plots for new and stockpile aged materials clearly indicates that aging is not affecting the shock initiation properties of PBX 9501. Figure 5, which showed particle velocity wave profiles for these materials, also showed no effects. Thus, in two ways we have demonstrated that stockpile aging does not affect the shock initiation properties of PBX 9501. If the PBX 9501 density is held constant, we see no difference in the initiation of aged explosives when compared to new explosives.

REFERENCES