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Title: INSIGHTS INTO THE SHOCK INITIATION/DETONATION OF HOMOGENEOUS AND HETEROGENEOUS HE

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Insights into the Shock Initiation/Detonation of Homogeneous and Heterogeneous HE

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It has long been known that there are fundamental differences between homogeneous and heterogeneous high explosives. The shock initiation behavior of these materials was first described in the literature by Campbell et al. in 1961.[1,2] Chaiken was also involved in describing this process for liquid nitromethane.[3] Since then, there have been a number of studies which have added considerable incite into the shock initiation/detonation behavior of these materials. We only give a few referneces here (Refs. 4 – 11) and these should be considered representative; e.g. they do not represent an exhaustive list of references available. Many of these studies were done on homogeneous explosives, most often nitromethane (NM) and include particle velocity gauge measurements, optical temperature measurements, VISAR measurements, as well as streak camera measurements of interfaces. In some cases NM was heterogenized by gelling and adding silica particles.

Homogeneous materials are typically liquids or single crystals in which there are a minimal number of physical imperfections (e.g. bubbles or voids) that can cause perturbations in the input shock and the flow behind it. Homogeneous materials viewed with macroscopic probes characteristic of detonation physics experiments appear uniform. Heterogeneous explosives are generally all other types; these are usually pressed, cast, machined, or extruded into the shapes or parts desired. These materials contain imperfections of a variety of types that cause fluid-mechanical irregularities (called hot spots) when a shock or detonation wave passes over them. Such hot spots cause associated space/time fluctuations in the thermodynamic fields (e.g., the pressure or temperature fields) in the material. These thermodynamic variations affect the local chemical-heat-release rate – they produce an average heat-release rate that is a combination of chemistry and mechanics. Hot spots could be the result of voids, shock interactions, jetting, shock impedance mismatches, etc.

Shock initiation of homogeneous explosives is due to a thermal explosion that occurs in the material shocked the longest. This reaction produces a reactive wave that grows behind the front and eventually overtakes the front. The reactive wave may grow into what is called a superdetonation before it overtakes the initial shock and settles down to a steady detonation. The shock initiation process in heterogeneous explosives differs a great deal because the hot spots cause early chemical reaction as soon as the shock passing over a region creates them. This causes reactive growth both in and behind the shock front. This leads to a relatively smooth growth of the initiating shock to a detonation, in contrast to the abrupt changes that occur in the homogeneous case. These differences are apparent in both the in-situ reaction wave profiles and the acceleration of the shock front.

In addition to differences in the shock initiation behavior, there are also differences in the diameter-effect curve (relationship between detonation velocity and inverse charge diameter) and the Pop-plot (relationship between input shock pressure and growth to detonation). In general, a homogeneous explosive has a shallow diameter-effect curve with very little decrease in detonation velocity before the failure diameter is reached (called the velocity deficit). NM has a velocity deficit of about 1%. Heterogeneous explosives have a diameter-effect curve that curves down as the diameter decreases and can have velocity deficits that are much greater. As an example, heterogenized NM has a velocity deficit of 10%, an order of magnitude greater than homogeneous NM.

With respect to Pop-plot differences, homogeneous explosives initiation behavior is very state sensitive; e.g., small changes in input shock pressure result in large changes in the time or distance to detonation. This is expected because the chemistry depends on a thermal explosion, an inherently state-sensitive process. In the case of heterogeneous materials, hot spots develop at the heterogeneities, stimulating chemical energy release locally and making the explosive initiate at much lower pressure inputs than would otherwise be the case. For example, pure liquid NM can be made to initiate, with a sustained shock input of about 8 to 9 GPa, in approximately 1 μs, whereas the same material with a large number of corundum heterogeneities will initiate in the same time interval with 2 to 3 GPa inputs. Because the hot spots produce reaction locally, heterogeneous explosives have much less-sensitive state-dependent chemical-energy-release rates than homogeneous materials. The dependence of the energy release on the bulk material pressure and temperature produced by the initiating shock (which is all important in the homogeneous case) is secondary.

Many of the common explosives used (PBX9501, PBX9502) have initiation/detonation properties that fall in between the purely homogeneous and purely heterogeneous cases. We have made a number of multiple magnetic gauge particle velocity measurements on these materials; some will be presented and discussed. These are all gun experiments in which the input to the explosives is well known because the projectile velocity is precisely measured and the impactor materials are well characterized. Examples of these measurements are shown in Figs. 1 and 2; the waveforms in these figures are particle velocity measurements at discreet Lagrangian positions in the flow There are eleven separate gauges in Fig. 1 and ten in Fig. 2. In Fig. 1 it is clear that the PBX9501 growth to detonation results from some growth in the front and considerable growth behind the front. We take this to mean that there is both a homogeneous and a heterogeneous nature to this reactive wave. In Fig. 2 the waveforms show much more growth in the front and less behind the front. We interpret this to mean that the PBX9502 initiation is more heterogeneous than is the case for the PBX9501. This is interesting and will be discussed in relation to some earlier diameter effect data on PBX9502 of Campbell and Engelke that suggests it has a more homogeneous nature.

The magnetic gauges we use have several "shock trackers" that track the shock front and can be plotted in a distance-time (x-t) diagram to give information about how the shock front accelerates during the initiation process. These data are plotted for Shot 1133 in Fig. 3. The shape of the curve indicates the acceleration is relatively rapid at the time the wave turns over to a detonation. This can be contrasted to the buildup in the PBX9502

experiment of Fig. 2; the x-t data are shown in Fig. 4. The acceleration is much more gradual for the PBX9502, the result of more reaction in the front and less behind the front. We present an empirical form for fitting to the x-t data and use this to compare the nature of the buildup process for these two materials.

We have also completed an experiment where the initiation process in isopropyl nitrate (IPN) has been measured with in-situ magnetic gauges. IPN is a relatively low output liquid explosive. The data from this experiment are shown in Fig. 5. These profiles show the superdetonation forming and it appears to have reached a near steady state before it overtakes the initial shock. This buildup process occurs faster than that observe in chemically sensitized NM. It appears that the exact details of the buildup process depend on the particular material and the chemistry that is going on during the initiation. In any case, these waveforms support the modified classical homogeneous initiation model.[9] Details of the wave growth and superdetonation velocity will be discussed in detail.

In summary, these new measurements and analysis add to the knowledge base for homogeneous/heterogeneous initiation and detonation phenomena. However, much more work will be required to work out the details relating to these processes. The solid composite HEs routinely used have both a heterogeneous and a homogeneous nature to them and the differences are measurable and can be quantified to some extent. The large number of in-situ measurements in a single experiment provides a body of data to challenge the reactive models being used in computations and provides a unique challenge for the modelers.

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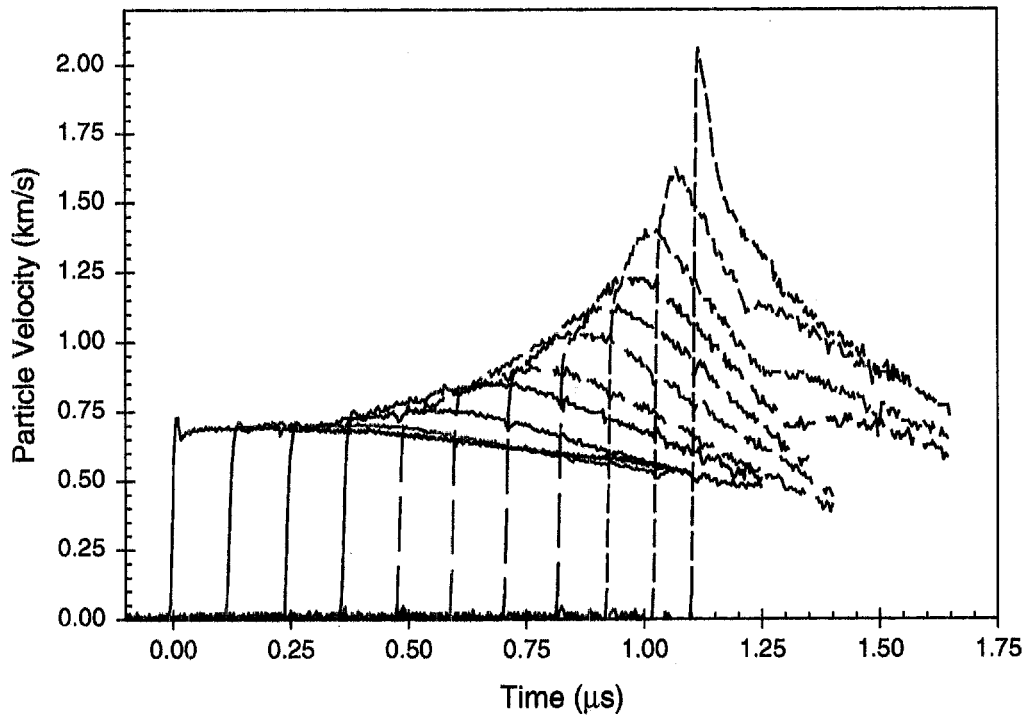
Figure 1. Particle velocity wave profiles from PBX9501 Shot 1133. The input was 5.15 GPa.
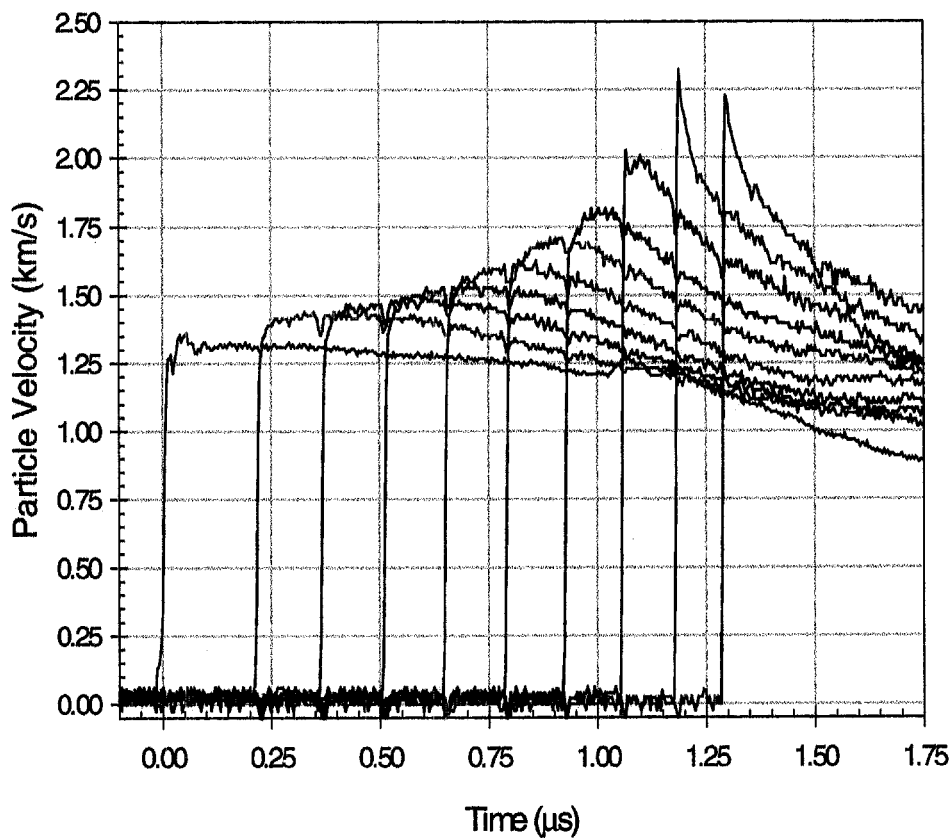

Figure 2. Particle velocity wave profiles from PBX9502 Shot 2s-40. The input was 13.5 GPa.
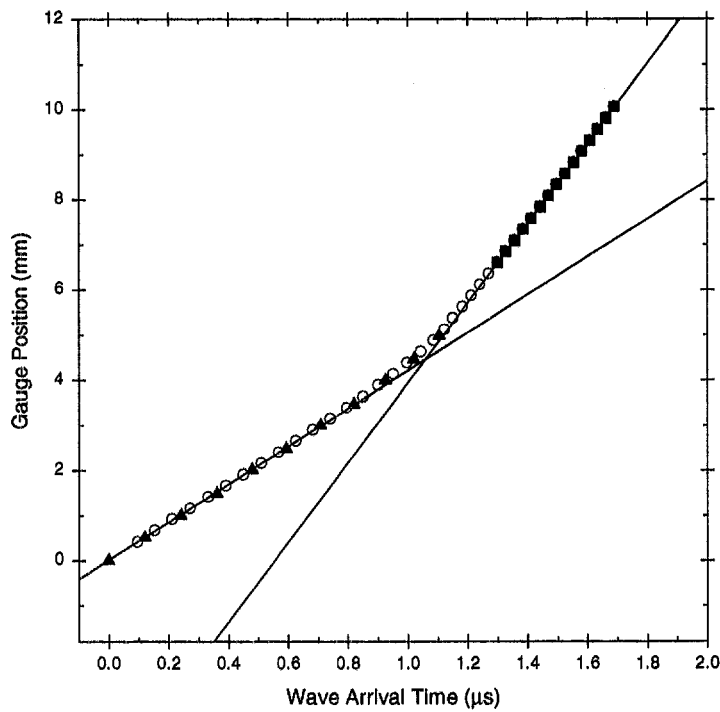
Figure 3. Distance-time (*x-t*) plot obtained from shock arrival at shock tracker points (before detonation--circles), shock tracker points (after detonation--squares) and particle velocity gauge points (triangles). Data are from Shot 1133, PBX9501.
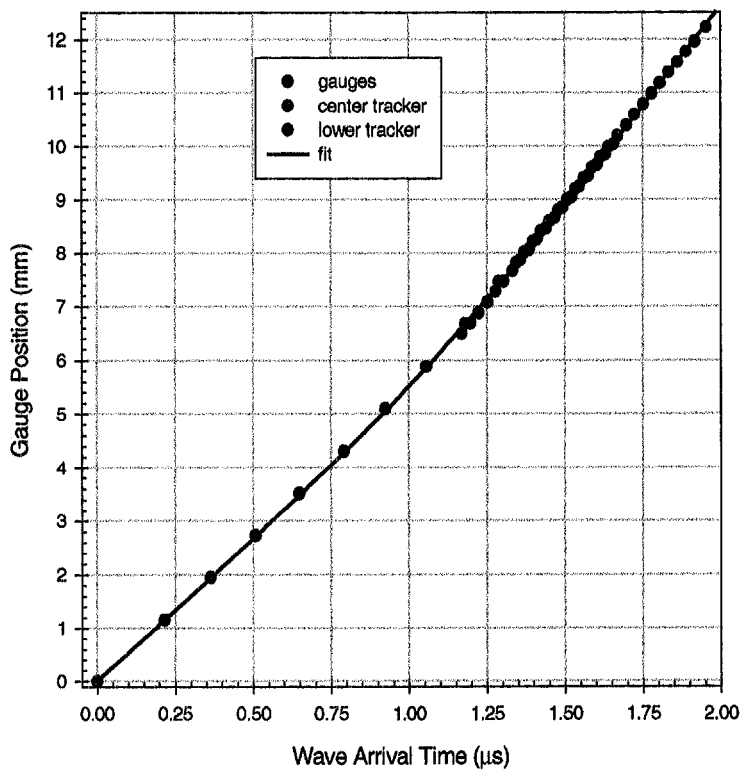

Figure 4. Distance-time (*x-t*) plot obtained from shock arrival at shock tracker points (close together circles), and particle velocity gauge points (far apart circle). Data are from Shot 2s-40, PBX9502.
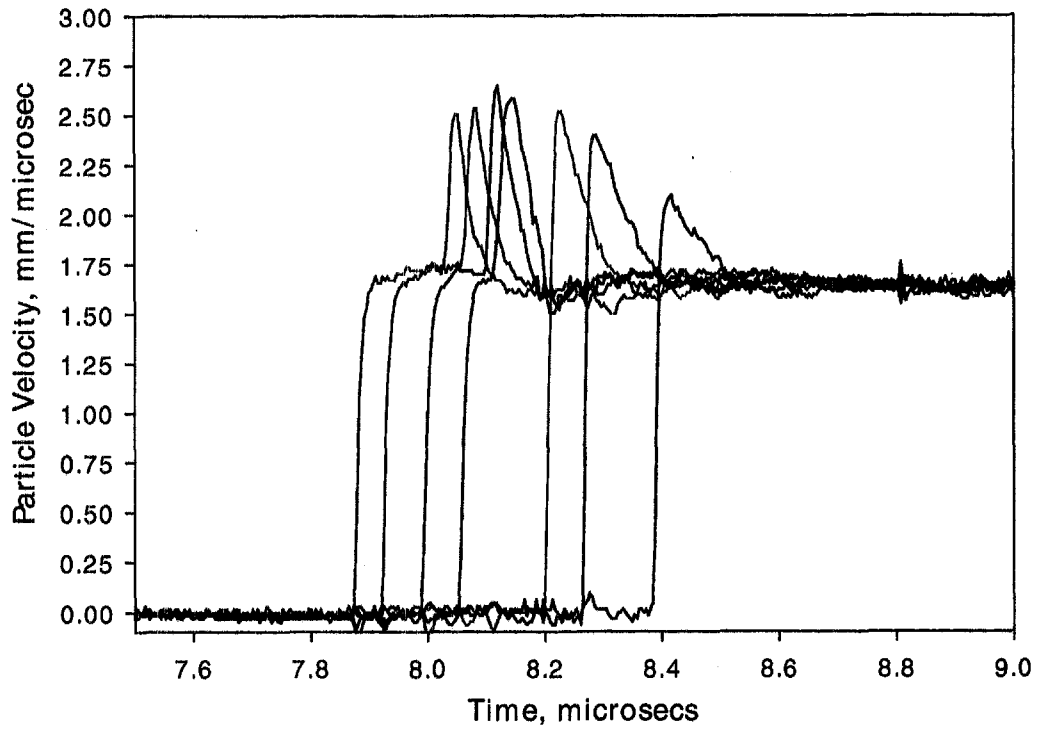
Figure 5. Particle velocity wave profiles from IPN Shot 2s-29. The input was 9.0 GPa.