The Shock-to-Detonation Transition in Explosives-an Overview

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Summary: Shock initiation of explosives occurs by two different mechanisms-either hot spotbased or thermal explosion-based-depending on microstructure. Studies on a large number of explosive compositions using *in-situ* electromagnetic gauging has established new insights into the reactive flow in the build-up to detonation, relative shock sensitivities, and their state dependencies.

Introduction

A foundational understanding of shock initiation of explosives is necessary for evaluating and comparing the shock sensitivities of various formulations, predicting run-distances to detonation, and ultimately designing explosive trains and assessing explosive response to accident scenarios. The nature of reactive flow associated with the build-up to detonation is linked to the dominating mechanism of initiation. In heterogeneous explosives, shock initiation occurs by the collective interactions of "hot spots" from which chemistry originates [1-4]. In homogenous explosives, including liquid explosives, initiation occurs via shock heating and thermal explosion [5, 6]. These two initiation mechanisms will be discussed with examples chosen to illustrate the spectrum of shock initiation behaviors in plastic-boned explosives, liquid explosives, and liquid explosives loaded with controlled hot spot "seeds". New experiments have also interrogated the response of PBX 9501 to complex shock loading conditions, including short shock and combined shock-shear conditions. These data are revealing the critical energy for initiation, and the role of shear in initiation under moderate-to-high shock pressures.

Results and Discussion

The shock-to-detonation transition in a variety of explosive materials has been investigated using embedded electromagnetic gauging techniques to obtain *in-situ* shock wave profiles at up to ten Lagrangian positions in the explosive. From the evolution of the shock and reactive waves (reactive flow), the run distance to detonation is determined, establishing Pop-plots (run-distance-to-detonation as a function of shock input pressure), in addition to initiation mechanisms, Figure 1, for a broad sample of explosives.

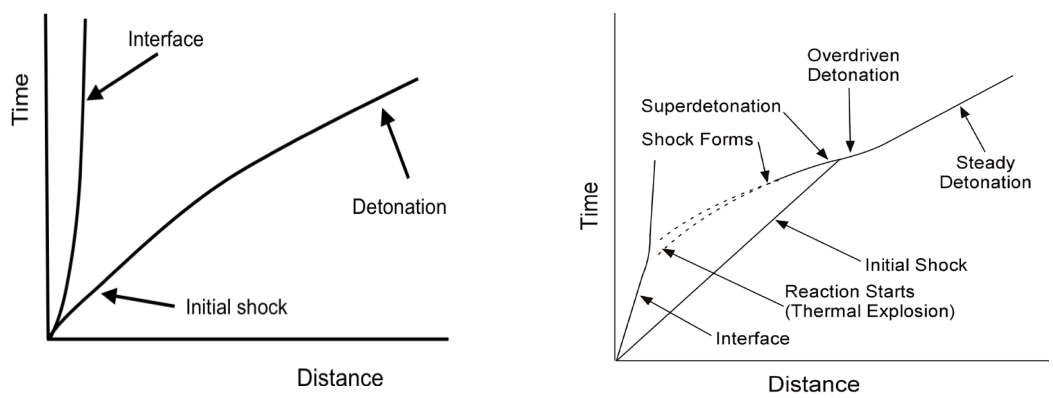

Figure 1. Time-distance (t-x) diagrams illustrating two mechanisms of shock initiation of explosives. (left) In heterogeneous explosives, the localization of energy in "hot spots" results in energy release close to the shock front and a nearly continuous acceleration of the initial shock wave into a detonation. (right) In homogenous explosives, initial shock compression is followed by thermal explosion, and a build-up of a reactive wave that eventually overtakes the front.

All of the *liquid explosives* studied to date (nitromethane, FEFO, IPN, and hydrogen peroxide/water) have been found to initiate via the modified homogeneous initiation model, Figure 1 (right). The data indicate that all liquid explosives have similar strong state sensitivities, as illustrated by similar slopes of their

respective Pop-plots. Small variations in the input shock pressure (and temperature) result in large variations in the run distances to detonation. Differences in sensitivity can be attributed to chemical structure.

Initiation in heterogeneous explosives is strongly dependent on microstructure. To investigate the role of hot spots in the initiation of heterogeneous explosives, well-defined solid and hollow silica particles (1-40 mm diameters) at several volumetric loadings were added to the gelled liquid explosive nitromethane. Measurement of the reactive flow indicated specific conditions of hot spot effectiveness vs. hot spot criticality. For example, we have found that 40 mm diam. glass microballoons at 1.2 wt% are effective hot spots, Figure 2 (left). Decreasing the volumetric loading to 0.36 wt% renders the hot spots nearly "critical", with the reactive flow showing evidence of competing homogeneous and heterogeneous mechanisms, Fig. 2 (right).

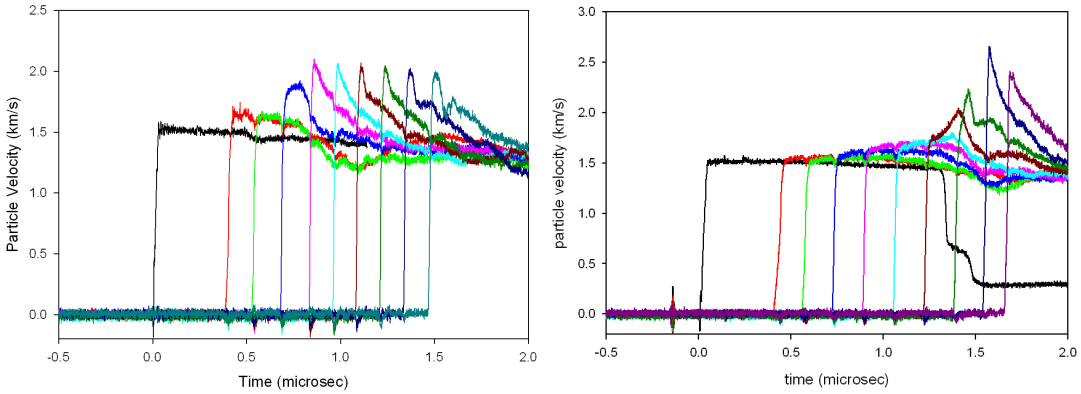

Figure 2. (Left) *In-situ* wave profiles from shot 2S-441, 96.98/1.2/1.84 NM/40 mm balloons/Guar, with an initial shock input pressure of 8.2 GPa showing hot spot-derived reactive growth. (Right) By contrast, spacing the microballons farther apart gives rise to a mixed mechanism, as seen in shot 2s-442, 97.79/0.36/1.85 NM/40 mm balloons/Guar with a shock input pressure of 8.1 GPa. There is evidence of thermal explosion, and the detonation is overdriven.

Conclusions

Shock initiation processes have been investigated for a number of different types of explosives at LANL. Liquid explosives all initiate via the homogenous initiation model. Model materials with hot spot "seeds" have enabled better understanding of hot spot effectiveness vs. criticality, and a possible means of tuning the reactive flow. We are now extending these types of measurements to complex loading and 2-D configurations.

Acknowledgements

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