LA-UR- 09-04939

Approved for public release; distribution is unlimited.

Title: DETONATION WAVE PROFILES MEASURED IN PLASTIC BONDED EXPLOSIVES USING 1550 NM PHOTON DOPPLER VELOCIMETRY (PDV)

Author(s): RL GUSTAVSEN, BD BARTRAM, NJ SANCHEZ

Intended for: SHOCK COMPRESSION OF CONDENSED MATTER - 2009 Conference Proceedings

Los Alamos NATIONAL LABORATORY EST.1943

DETONATION WAVE PROFILES MEASURED IN PLASTIC BONDED EXPLOSIVES USING 1550 nm PHOTON DOPPLER VELOCIMETRY

R. L. Gustavsen, B. D. Bartram, and N. J. Sanchez

Los Alamos National Laboratory, Los Alamos NM 87545

Abstract. We present detonation wave profiles measured in two TATB based explosives and two HMX based explosives. Profiles were measured at the interface of the explosive and a Lithium-Fluoride (LiF) window using 1550 nm Photon Doppler Velocimetry (PDV). Planar detonations were produced by impacting the explosive with a projectile launched in a gas-gun. The impact state was varied to produce varied distance to detonation, and therefore varied support of the Taylor wave following the Chapman-Jouget (CJ) or sonic state. Profiles from experiments with different support should be the same between the Von-Neumann (VN) spike and CJ state and different thereafter. Comparison of profiles with differing support, therefore, allows us to estimate reaction zone lengths. For the TATB based explosive, a reaction zone length of ≈ 3.9 mm, 500 ns was measured in EDC-35, and a reaction zone length of ≈ 6.3 mm, 800 ns was measured in PBX 9502 pre-cooled to -55°C. The respective VN spike state was 2.25 ± 0.05 km/s in EDC-35 and 2.4 ± 0.1 km/s in the cooled PBX 9502. We do not believe we have resolved either the VN spike state (> 2.6 km/s) nor the reaction zone length (<< 50 ns) in the HMX based explosives.

Keywords: Reaction zone, ZND, Taylor wave, PDV, TATB, HMX.
PACS: 47.70.-n, 47.40.Rs, 42.79.Qx.

INTRODUCTION

The structure of the detonation reaction zone in plastic bonded explosives has been widely studied using optical velocimetry methods.[1-6] Recently, Strand et al.[7] introduced a new velocimetry technique based on 1550 nm fiber lasers and single-mode fiber-optic telecommunications components. These methods have become known in the United States as Photon Doppler Velocimetry, or PDV. Because the high time resolution required for measurement of the detonation front, and because of the very high bandwidth (6 – 20 GHz) digitizers and detectors used in PDV measurements, we thought it would be instructive to try this new method for the study of the detonation reaction zone.

EXPERIMENTAL METHODS

PDV Interferometer

Pertinent details of the PDV interferometer used for these studies are as follows. First, the same laser was used to provide reference light and send light to the moving reflector. (PDV systems can be constructed with a second laser with slightly different wavelength to provide the reference light.) Doppler shifted laser light reflected from the moving interface was mixed with the reference light at the detector. The detector was a Miteq (www.miteq.com) DR-125G with a 13 GHz bandwidth. Signals were recorded at 40 ps/point (25 samples/ns) on a Tektronix (www.tek.com) DPO 70604 digitizer which has a 6 GHz analog bandwidth.

It is worth noting that the von Neumann (VN) spike, viewed through a Lithium Fluoride (LiF) window, will have an apparent velocity of ≈ 3 km/s. 1550 nm light Doppler shifted at 3 km/s and mixed with unshifted light will produce beat frequencies of ≈ 4 GHz. Equivalently, this is only 4 beat cycles or fringes per ns. This highlights the need for fast detectors and digitizers.

Time-frequency analysis of PDV signals

PDV signal data was analyzed using a sliding-window or Short-Time-Fourier-Transform with a Gaussian window. In the signal processing literature, this is known as the Gabor transform. An exhaustive introduction to the mathematics of this transform is given by Gröchenig[8]. With the Gabor transform, the width of the Gaussian can be arbitrarily chosen, but its choice defines both the time resolution and the smoothness of the resulting velocity vs. time curves. For the present experiments, we chose a Gaussian with Full Width at Half Maximum (FWHM) of 2ns. This produces wave profiles with reasonable smoothness and the 2 ns time resolution is comparable to that achieved with VISARs.[4,6] Our analysis was programmed using Mathematica. (www.wolfram.com)

Detonation wave profile experiments

A schematic of the detonation wave profile experiment is shown in Fig. 1. A flyer plate, mounted on a projectile, is launched in a gas gun.

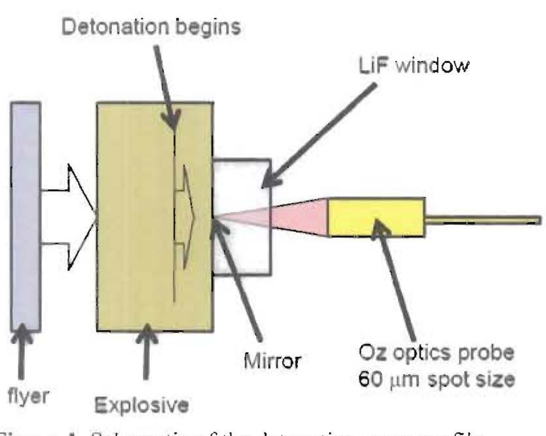

Figure 1. Schematic of the detonation wave profile experiment.

Upon impact, a shock wave is launched into the explosive. This evolves into a detonation which collides with the LiF window. The interferometer measures the velocity of the explosive/LiF window interface.

Because the "apparent" velocity of the reflector viewed through a shocked window is higher than the true velocity, a "window correction factor" must be applied. Jensen et al. [9] recently measured 1550 nm correction factors for the LiF window material used here as well as c-cut Sapphire, and z-cut Quartz.

Explosive samples were 50.8 mm diameter by 23 mm thick. Composition, density, and initial temperature of each explosive tested will be given in the results section. LiF windows were high purity (100) oriented single crystals obtained from Reflex Analytical (www.reflexusa.com). Back surfaces of the windows were anti-reflection coated, and the dimensions were 25.4 mm diameter by 12.7 mm thick. Mirrors were aluminum and either vapor plated on the window or in the form of a 6 μm thick foil.

Probes, to send and receive light from the mirror were made by Oz Optics (www.ozoptics.com) part # LPF-01-1300/1550-9/125-S-10-21-2AS-40-3S-3-3. The front focal length of this probe is 21 mm and the spot size is ≈ 60 μm. This spot size is comparable to the grain size of the explosives.

Figure 2 shows a schematic representation of the detonation wave profile. The shock front moves into unreacted material, hence the von Neumann (VN) spike state must be on the unreacted Hugoniot for the explosive. In the reaction zone, explosives are converted into

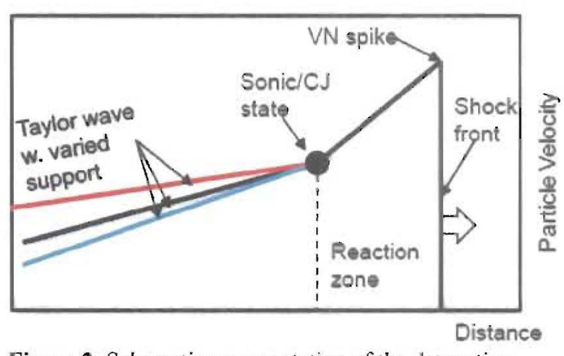

Figure 2. Schematic representation of the detonation wave profile.

products. After the sonic or Chapman-Jouguet (CJ) state comes a Taylor wave.

Between the VN spike and CJ state, detonation wave profiles should be identical, irrespective of the initiation conditions or the explosive thickness. By varying the impact pressure, we can vary the point where detonation begins, and the overall support of the Taylor wave. By comparing profiles obtained in experiments with different initiation conditions or which have different thicknesses, we can gain information about both the reaction zone length, and the CJ state. This is a method first used by Seitz et al.[3]

RESULTS AND DISCUSSION

Detonation wave profiles for 4 experiments on EDC-35 (95 weight % TATB, 5 weight % Kel-F 800 binder, 1.900 g/cm^3) are shown in Fig. 3. There is a fast drop in particle velocity in the first 10 – 20 ns followed by a slower drop. This indicates a fast, followed by a slow reaction. The observed VN spike point is 2.25± 0.05 km/s. This is only slightly higher than the 2.19± 0.05 km/s recorded by Seitz et al.[3] for PBX 9502 using a Fabry-Perot.

Taylor waves begin to diverge at ≈ 0.50 μs. The corresponding reaction zone length would be 3.9 mm. This is in rough agreement with the estimate of 2.1 mm given by Sheffield, Bloomquist, and Tarver[1] from ORVIS measurements, the estimate of 2.9 mm given by Wescott, Stewart and Davis[10] from a reactive burn calibration, and the estimate of 4.9 mm from Aslam and Hill's fit to the diameter effect curve. [11]

Detonation wave profiles for PBX 9502 which was pre-cooled to -55°C are shown in Fig. 4. PBX 9502 has the same composition as EDC-35, but a lower room temperature density of 1.890 g/cm^3. Results from 8 experiments with 5 different input conditions are shown in Fig. 4. As with EDC-35, there is a fast, 10 – 20 ns, drop in particle velocity followed by a slower drop. Again, fast and slow reactions are implied. The observed VN spike point is 2.4± 0.1 km/s. This is higher than observed in EDC-35 and probably due to the increased density of the cooled explosives.

In Fig. 4, Taylor waves begin to diverge at ≈ 0.80 μs. The corresponding reaction zone length would be 6.3 mm. This is in excellent agreement with the estimate of 6.3 – 7.4 mm (depending on lot) from Aslam and Hill's fit to temperature dependent diameter effect data in PBX 9502 [11].

Figs. 5 and 6 show detonation wave profiles in the HMX based explosives EDC-29 and PBXN-9. EDC-29 is 95 wt. % HMX, 5 wt. % polyurethane binder. PBXN-9 is 92 wt. % HMX, 6 wt. % dioctyl-adipate, and 2 wt. % Hycar. HMX particles in PBXN-9 were rather large (≈ 200 μm).

Comparison of Figs. 5 and 6 with Figs. 3 and 4 shows detonation wave profiles in the HMX based explosive are much noisier than those in the TATB based explosives. This is likely caused by the 60 μm diameter circle sampled by the interferometer compared with the explosive grains which have a characteristic size of 150 μm. There are likely

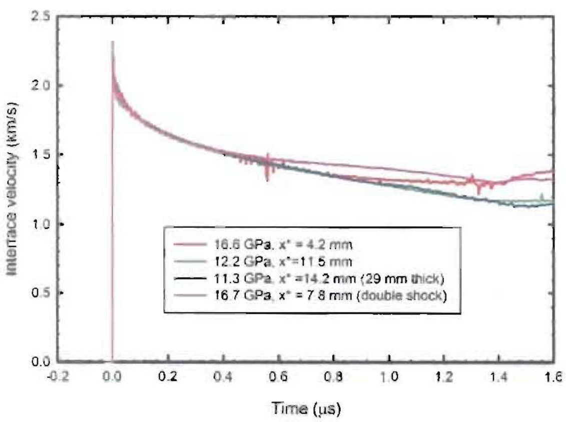

Figure 3. Detonation wave profiles for EDC-35 at initial temperature of 23°C.

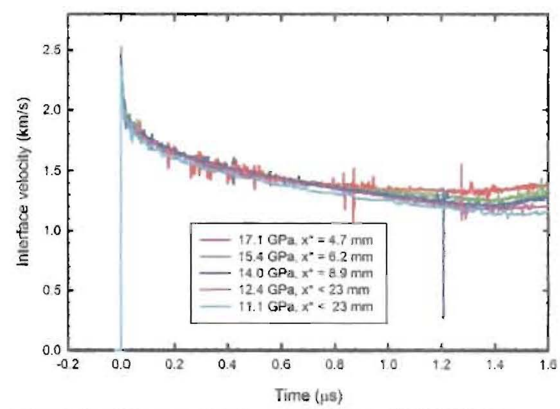

Figure 4. Detonation wave profiles for PBX 9502 at initial temperature of -55°C.

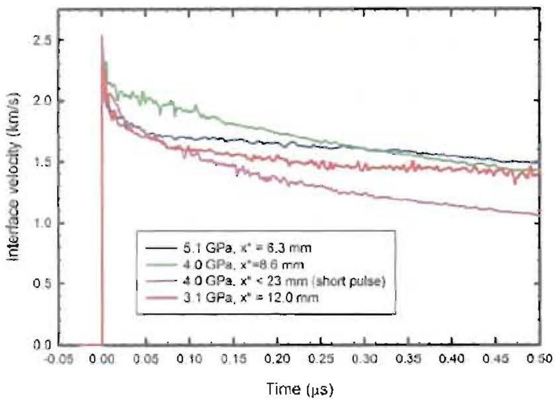

Figure 5. Detonation wave profiles for EDC-29.

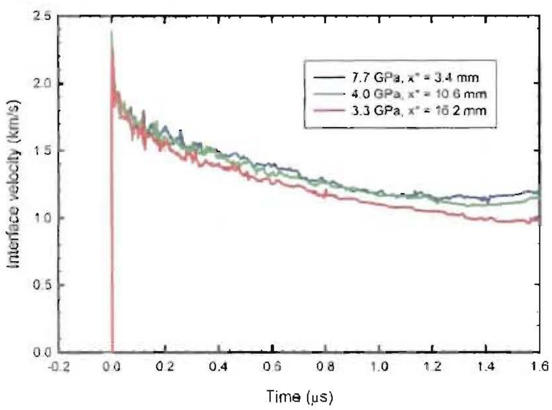

Figure 6. Detonation wave profiles for PBXN-9.

grain-scale hydrodynamic fluctuations which are not well averaged by the small laser spot. By contrast, the TATB based explosives have characteristic grain sizes of order 50 μm.

In both Figs. 5 and 6, Taylor waves begin to diverge at < 50 ns; the exact time is difficult to determine. Menikoff[12] has estimated reaction zone parameters at 90% burn for PBX 9501. (The estimates for PBX 9501 should be relevant because it is 95% HMX.) According to Menikoff, the reaction zone length is 24 μm or 3 ns. Menikoff also estimated the VN spike point matched into a LiF window as ≈ 2.9 km/s. While the VN spike condition shown in Figs. 5 and 6 is above the CJ state of ≈ 2.1 km/s, we are clearly not accurately resolving it. Neither have we resolved, with this instrument and analysis, the ≈ 3 ns reaction zone in these HMX based explosives.

REFERENCES

1. Sheffield, S. A., Bloomquist, D. D., and Tarver, C. M., "Subnanosecond measurements of detonation fronts in solid high explosives", *The Journal of Chemical Physics*, 80 (8), 3831 (1984).
2. Seitz, W. L., Stacy, H. L., and Wackerle, J., "Detonation Reaction-Zone Studies on TATB Explosives", in Eighth Symposium (International) on Detonation, (Short, J. M. eds.), pp. 123, (1985).
3. Seitz, W. L., Stacy, H. L., Engelke, R. P., Tang, P. K., and Wackerle, J., "Detonation Reaction-Zone Structure of PBX 9502", in Ninth Symposium (International) on Detonation, (Lee, E. L. and Short, J. M. eds.), pp. 657, (1989).
4. Gustavsen, R. L., Sheffield, S. A., and Alcon, R. R., "Detonation wave profiles in HMX based explosives", in Shock Compression of Condensed Matter - 1997, (Schmidt, S. C., Dandekar, D. P., and Forbes, J. W. eds.), pp. 739, (1998).
5. Lubyatinsky, S. N. and Loboiko, B. G., "Detonation reaction zones of solid explosives", in Eleventh International Detonation Symposium, (Short, J. M. and Kennedy, J. E. eds.), pp. 836, (1998).
6. Gustavsen, R. L., Sheffield, S. A., and Alcon, R. R., "Progress in measuring detonation wave profiles in PBX 9501", in Eleventh International Detonation Symposium, (Short, J. M. and Kennedy, J. E. eds.), pp. 821, (1998).
7. Strand, O. T., Goosman, D. R., Martinez, C., Whitworth, T. L., and Kuhlow, W. W., "Compact system for high-speed velocimetry using heterodyne techniques", *Review of Scientific Instruments*, 77 (2006).
8. Gröchenig, K., "Foundations of Time-Frequency Analysis". (Birkhäuser, Boston, MA, 2001).
9. Jensen, B. J., Holtkamp, D. B., Rigg, P. A., and Dolan, D. H., "Accuracy limits and window corrections for photon Doppler velocimetry", *Journal of Applied Physics*, 101, 013523 (2007).
10. Wescott, B. L., Stewart, D. S., and Davis, W. C., "Equation of state and reaction rate for condensed phase explosives", *Journal of Applied Physics*, 98 (5), 053514 (2005).
11. Aslam, T. D. and Hill, L. G., "Detonation Shock Dynamics Calibration for PBX 9502 with Temperature, Density, and Material Lot Variations". (Unpublished report, Los Alamos, NM, 2008).
12. Menikoff, R., "Detonation Wave Profile in PBX 9501", in Shock Compression of Condensed Matter - 2005, (Furnish, M. D., Elert, M., Russell, T. P., and White, C. T. eds.), pp. 986, (2006).