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FY18 J23X PDZG Final Report: Double Shock Initiation of PBX 9502 Lot HOL88H891-008

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Heterogeneous high explosives subjected to sub-critical shock waves are known to exhibit desensitization to later shock inputs. While it is believed that this phenomenon is due to the removal of hot spot forming features in the explosive by the initial sub-critical shock, the effect of the time delay between the shocks is poorly understood. This report details a series of double shock plate impact experiments that vary the time between similar shocks to explore the time dependance of this shock desensitization process. These experiments were performed on the insensitive explosive PBX 9502 (95% TATB, 5% Kel-F 800) with lot number HOL88H891-008. The evolution of the shocks to a detonation was characterized by 9 embedded magnetic particle velocity gauges, and 116 embedded magnetic time of arrival gauges (AKA shock trackers). Photon Doppler velocimetry (PDV) with a LiF window was used at the back surface of the samples to capture the wave profile exiting the sample. Three double shock experiments were performed, with first and second shock pressures of 8.3 GPa and 16.5 GPa, respectively. An analogous single shock experiment at 16.3 GPa was also performed. The double shock experiments exhibited small levels of reaction during the initial shock, and shock desensitization to the second shock. Run distances after shock coalescence were shorter than those expected for a single shock, indicating the shock to detonation transition (SDT) process was slightly further along due to partial reaction in the first shock wave. These data will be used to calibrate model behavior under multiple-shock conditions. Additional double shock data will be collected to further explore this area in FY2019. All data have been uploaded to the LANL Small Scale Database for use by the research community.

I. INTRODUCTION

In complex explosive systems, especially those in which the HE in is contact with metals or forms convoluted geometries, shock waves from a detonating portion of the assembly may be transmitted ahead of the detonation wave. Even if these shocks are sub-critical (i.e. insufficient to lead to a detonation) they can still effect the performance of the explosive system by creating 'dead zones', which are areas with reduced shock sensitivity. This effect has been observed in multiple heterogeneous explosives,[1–5] and appears to be related to the elimination of voids in the sub-critically shocked explosive, leaving the shocked material with fewer sites to ignite as hot spots under a subsequent shock. It has been noted in the literature that this process is likely time dependent,[3] but there have been no systematic experiments to explicitly vary the time between two shocks and observe the effect on the SDT process.

In this work, gun-driven layered Kel-F81/sapphire impactors are used to generate precisely-controlled double shock inputs into samples of PBX 9502 (95% TATB, 5% Kel-F 800) with lot number HOL88H891-008. A series of two shocks with amplitudes of 8.3 and 16.5 GPa are produced, with Δt between the shocks of 187–780 ns. Response of the explosive is recorded by an embedded particle velocity gauge technique[6]. These gauges provide a detailed look at the SDT process by capturing particle velocity histories at multiple locations as chemical reactions develop behind the shock(s) and ultimately forms a detonation.

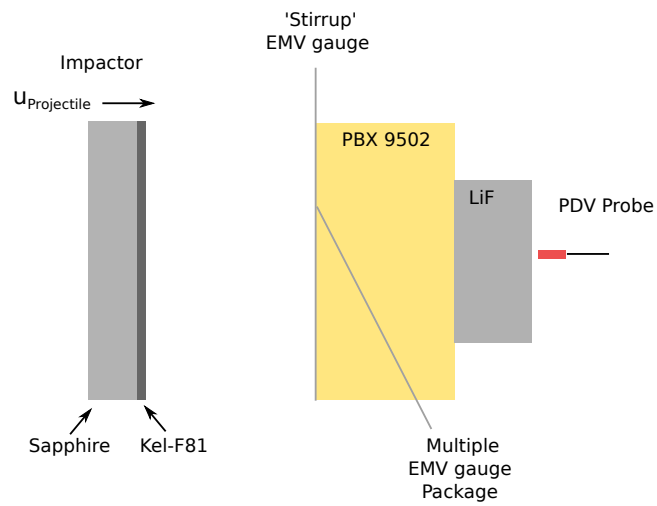


FIG. 1. Schematic of the setup used in these experiments. An embedded gauge is glued between a pair of PBX 9502 wedges and impacted by a layered Kel-F81 & sapphire impactor.

II. EXPERIMENTAL SETUP

All experiments were conducted on the LANL TA-40 Chamber 9 two-stage gas gun. Billets of PBX 9502 lot HOL88H891-008 were isostatically pressed at 110 degrees C to a nominal density of 1.89 g/cc, and machined into right cylindrical wedges with a 30 degree wedge angle. Pairs of wedges were assembled into right cylinders (nominally 43mm⌀ and 23 mm tall) with an embedded electromagnetic velocity (EMV) gauge package glued between them. Each gauge package includes 9 particle velocity

TABLE I. Summary of this series of double shock experiments in PBX 9502. P and u_p were calculated based on impedance matching with the Aslam 2017 PBX 9502 reactant EOS. Second shock pressures are approximate and should be modeled using the full EOS for greater accuracy.

Shot #	ρ_0 g/cc	Impactor	Impactor Vel. km/s	P, Shock 1 Gpa	P, Shock 2 Gpa	u_p Shock 1 km/s	u_p Shock 2 km/s	x_D mm	t_D us
2s-1038	1.892 ±0.001	Sapp.	1.972 ±0.001	16.3 ±0.3	-	1.53 ±0.025	-	3.3 ±0.2	0.56 ±0.05
2s-1045	1.891 ±0.001	0.5 mm Kel-F/Sapp.	1.976 ±0.001	8.2 ±0.3	∼16.4	0.95 ±0.025	1.54 ±0.025	4.7 ±0.2	0.88 ±0.05
2s-1046	1.890 ±0.001	1 mm Kel-F/Sapp.	1.992 ±0.001	8.3 ±0.3	∼16.6	0.96 ±0.025	1.54 ±0.025	6.7 ±0.2	1.39 ±0.05
2s-1047	1.891 ±0.001	2 mm Kel-F/Sapp.	1.989 ±0.003	8.3 ±0.3	∼16.5	0.96 ±0.025	1.53 ±0.025	10.4 ±0.2	2.13 ±0.05

gauges beginning at a nominal depth of 1 mm with 0.8 mm spacing between them. In addition, each package includes 'shock tracker' elements, which provide a time of arrival diagnostic at 116 points between 1.2–12.2 mm of depth in the target. A 'stirrup' EMV gauge was also glued to the impact face of the target. The gauges consist of Al conductors sandwiched between FEP Teflon, and produce a voltage proportional to local particle velocity as they move through a static magnetic field[6]. All glue bonds were made with with EPO-TEK 301 epoxy, with typical bond thicknesses of 1–2 microns. The configuration of this experiment is shown in Fig. 1. Two photon Doppler velocimetry (PDV) probes were used to obtain wave profiles on the back surface of the target through an Al coated 25 mm⌀ x 12 mm LiF window.

A total of 3 double-shock experiments were conducted using layered Kel-F81/sapphire impactors. Thickness of the Kel-F81 layer was 0.5, 1, and 2 mm to produce Δt between the shocks of 190, 400, and 780 ns. Full details of each experiment, including geometry and density of the HE samples, impactor and window thicknesses, gauge locations, x-t plots, and tabulated particle velocity data are available for each experiment on the LANL small scale database.

III. RESULTS

Table I lists summary data for all the PBX 9502 shots in this series. Impact conditions are calculated by impedance matching. The equations of state used for the Kel-F81, Sapphire, and PBX 9502 were obtained from references by Sheffield, Marsh, and Aslam, respectively.[7–9]

A. Wave Profiles

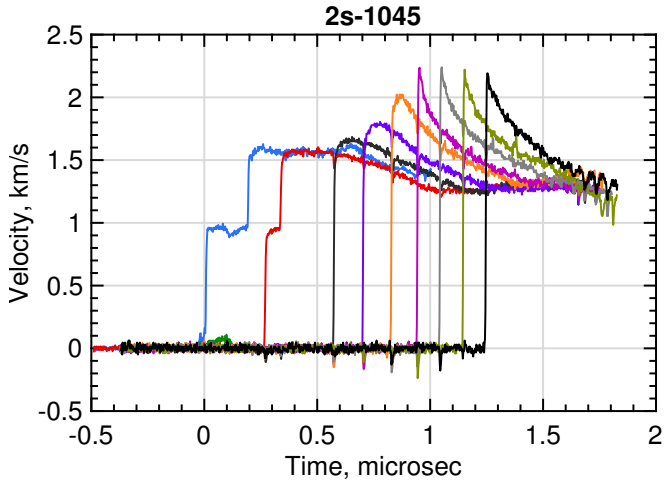
Figure 2 shows wave profiles from the embedded electromagnetic particle velocity gauges from all three double shock experiments. In all cases a small upward trend is observed behind the first (low amplitude) shock, indicating some reactivity is present. After the arrival of the second shock, the level of reactivity appears to be similar to that behind the second shock- no obvious reinforcement of the reaction initiated by the first shock is observed. After the shocks coalesce (at 2.0, 3.5, and 7.5 mm, in shots 1045, 1046, and 1047, respectively) reaction rates increase dramatically. This final coalesced shock is entering fresh material that has not been desensitized by a previous shock and SDT proceeds as expected in a heterogeneous explosive[10]. Run distances to detonation were calculated both in the traditional manner (measuring from the impact face of the sample), and by measuring from the point of shock coalescence. Traditionally calculated run distances show significant extension over a similar single shock experiment, which shows that the pre-shocked material is desensitized to the action of the second shock. When measuring from the point of shock coalescence, run distances are $0.3 - 0.8 \pm 0.2$ mm shorter than those expected from the single shock Pop plot.

B. Photon Doppler Velocimetry

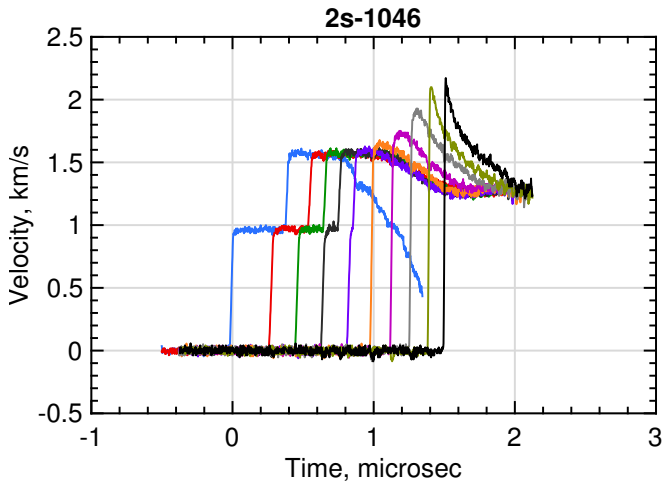
PDV wave profiles were obtained from the output surface of each sample (nominally 23 mm from the impact face) through a LiF window. A window correction was made based on the methods of Rigg.[11] In all cases a similar interface velocity, consistent with a detonation wave, was observed; for brevity only one PDV wave profile is reproduced here (shot 2s-1047).

C. PBX 9502 Pop-plot

Figure 4 shows the published Pop-plot of PBX 9502 at 296 K (solid line)[12], single shock experiments on this lot of explosive (red circles) and the run distances after shock coalescence in these double shock experiments (green circles). In all cases, the run distance of the coalesced shock is shorter than that expected from a single shock experiment at that pressure. This indicates that heating/reaction that occurred during the first low pressure shock contributed energy to the coalesced shock, reducing its run to detonation. This is similar to a single observation on the HMX-based explosive EDC32 made by Burns et. al.[2].



(a)



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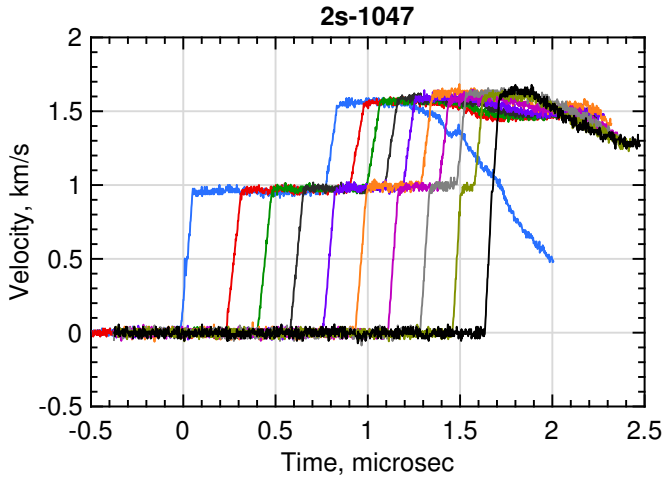

(c)

FIG. 2. Wave profiles from embedded particle velocity gauges; (a) Δt = 187 ns (shot 2s-1045), (b)Δt = 394 ns (shot 2s-1046),(c)Δt = 780 ns (shot 2s-1047)

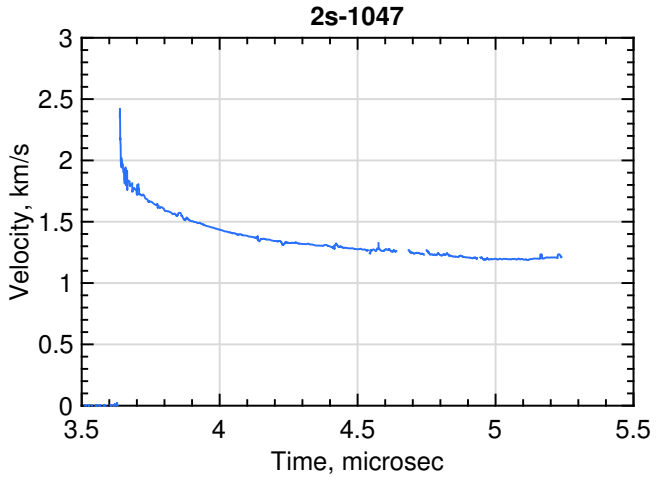

FIG. 3. Window-corrected velocity from PDV on back face of target (shot 2s-1047).

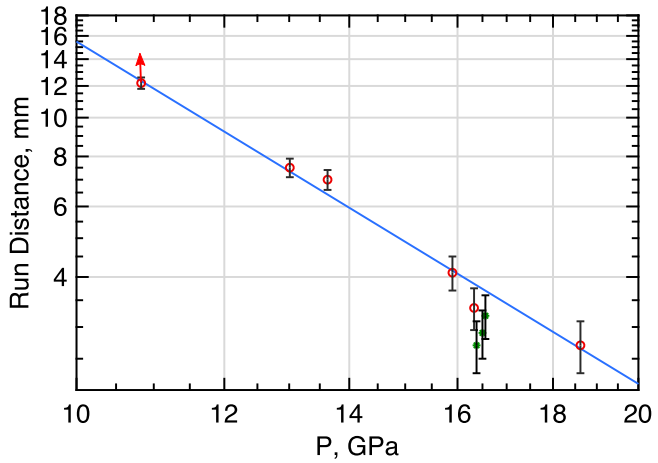

FIG. 4. Pop-plot for PBX 9502 from Gustavesen[12] (line), and single shock experiments on this lot (red circles).

IV. CONCLUSION

A series of plate impact, double shock, SDT experiments were performed on PBX 9502 lot HOL88H891-008 using the two-stage gas gun facility at TA-40 Chamber 9. Lot HOL88H891-008 is a virgin lot containing no recycled material. Shock conditions of 8.3 and 16.5 GPa were held constant, while variation in the Δt between the shocks (190, 400, and 780 ns) was explored. SDT was observed by an embedded magnetic particle velocity and time of arrival gauge, and detonation wave profiles were observed at the back surface of the samples by PDV. In all cases, only a small acceleration in the particle velocity (reactivity) was observed behind the first shock. Arrival of the second shock did not qualitatively increase the acceleration of particle velocity, indicating desensitiztion by the first shock. Only after the two shocks coalesced and entered unshocked material was a significant increase in reactivity observed. After coalescence, all samples com-

pleted SDT in a slightly shorter distance than predicted from a single shock, indicating the minor reaction behind the first shock did contribute to the SDT process. All data have been uploaded to the LANL small scale database for use in calibration and verification & validation of computational models.

V. REFERENCES

[1] A. W. Campbell, W. C. Davis, J. B. Ramsay, and J. R. Travis, "Shock initiation of solid explosives," *The Physics of Fluids*, vol. 4, no. 4, pp. 511–521, 1961.

[2] M. J. Burns, R. L. Gustavsen, and B. D. Bartram, "One-dimensional plate impact experiments on the cyclotetramethylene tetranitramine (hmx) based explosive edc32," *Journal of Applied Physics*, vol. 112, no. 6, p. 064910, 2012.

[3] K. Vandersall, C. Tarver, F. Garcia, S. Chidester, P. Urtiew, and J. Forbes, "Low amplitude single and multiple shock initiation experiments and modeling of lx-04," *13th International Detonation Symposium*, p. 908, 2006.

[4] P. Zi, J. Chen, R. Zhang, B. Zhong, and X. Zhang, "Double shock experiments on pbx explosive job-9003," *Propellants, Explosives and Pyrotechnics*, vol. 42, p. 784, 2017.

[5] T. Aslam, R. Gustavsen, N. Whitworth, L. H.J., B. Lambourn, C. Handley, J. H.R., and S. Root, "Multi-shock and isentropic compression of the tri-amino-tri-nitro-benzene based explosive pbx 9502: Evaluation of reactive flow models," *15th International Detonation Symposium*, p. 1166, 2014.

[6] S. Sheffield, G. R.L., and R. Alcon *APS Shock Compression of Condensed Matter - 1999*, p. 1043, 1999.

[7] S. P. Marsh, "Lasl shock hugoniot data," *University of California Press*, 1980.

[8] S. A. Sheffield and R. R. Alcon, "In-situ magnetic gauge measurements in kel-f," *Shock Compression of Condensed Matter - 1991*, 1991.

[9] T. D. Aslam, "The reactants equation of state for the tri-amino-tri-nitro-benzene (tatb) based explosive pbx 9502," *Journal of Applied Physics*, vol. 122, no. 3, p. 035902, 2017.

[10] D. D.M., S. A. Sheffield, S. D.B., D. A.M., T. W., and E. R., "Influence of hot spot features on the initiation characteristics of heterogeneous nitromethane," *14th International Detonation Symposium*, p. 611, 2010.

[11] P. A. Rigg, M. D. Knudson, R. J. Scharff, and R. S. Hixson, "Determining the refractive index of shocked [100] lithium fluoride to the limit of transmissibility," *Journal of Applied Physics*, vol. 116, no. 3, p. 033515, 2014.

[12] R. L. Gustavsen, B. D. Bartram, L. L. Gibson, A. Pacheco, J. D. Jones, and A. B. Goodbody, "Shock initiation of the tatb-based explosive pbx 9502 heated to 130°c," *AIP Conference Proceedings, APS SCCM St. Louis*, 2017.