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SHOCK INITIATION EXPERIMENTS ON PBX9501 EXPLOSIVE AT 150°C FOR IGNITION AND GROWTH MODELING

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Abstract. Shock initiation experiments on the explosive PBX9501 (95% HMX, 2.5% estane, and 2.5% nitroplasticizer by weight) were performed at 150°C to obtain in-situ pressure gauge data and Ignition and Growth modeling parameters. A 101 mm diameter propellant driven gas gun was utilized to initiate the PBX9501 explosive with manganin piezoresistive pressure gauge packages placed between sample slices. The run-distance-to-detonation points on the Pop-plot for these experiments showed agreement with previously published data and Ignition and Growth modeling parameters were obtained with a good fit to the experimental data. This parameter set will allow accurate code predictions to be calculated for safety scenarios involving PBX9501 explosives at temperatures close to 150°C.

INTRODUCTION

Interest exists in studying safety to shock impact of HMX (octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine) based explosives such as the commonly used PBX 9501 (95% HMX, 2.5% estane, and 2.5% BDNPA-F nitroplasticizer by weight), especially at elevated temperatures where the relative sensitivity to shock increases. Prior studies on PBX 9501 include wedge tests [1], embedded particle velocity gauges [2-4], VISAR at low input shock pressures [5,6], and embedded manganin gauges [7] at both ambient and elevated temperature. Another HMX based explosive, LX-04 (85% HMX, 15% Viton) has also been studied extensively at elevated temperatures [7,8]. In this paper, the shock sensitivity of PBX 9501 at 150˚C was measured using embedded manganin pressure gauges.

EXPERIMENTAL PROCEDURE

Shock initiation experiments were performed on the explosive PBX 9501 using the 101 mm diameter propellant driven gas gun at Lawrence Livermore National Laboratory (LLNL). Figure 1 shows a description of a typical experiment. The projectile consisted of a polycarbonate sabot with a 6061-T6 Aluminum flyer plate on the impact surface. As seen in Figure 1, the target includes buffer plates in contact with the high explosive at both the front and rear of the assembly to hold the material in place and sandwich the nichrome heater foils. The explosive was in the form of thin disks with gauge packages inserted in between with the total explosive thickness being 20 mm. The manganin piezoresistive foil pressure gauges placed within the explosive sample were "armored" with sheets of Teflon insulation on each side of the gauge. Manganin is a copper-manganese alloy that changes electrical resistance with pressure (i.e. piezoresistive). Also used were PZT Crystal pins to measure the projectile velocity and tilt (planarity of impact). During the experiment, oscilloscopes measure change of voltage as result of resistance change in the gauges which were then converted to pressure using the hysteresis corrected calibration curve published elsewhere [9,10].

From the data of the shock arrival times of the gauge locations, a plot of distance vs. time ("x-t plot") is constructed with the slope of the plotted lines yielding the shock velocities with two lines apparent, a line for the un-reacted state as it reacts and a line representing the detonation velocity. The intersection of these two lines is taken as the "run-distance-to-detonation," which is then plotted on the "Pop-Plot" showing the run-distance-to-detonation as a function of the input pressure in log-log space.

REACTIVE FLOW MODELING

The Ignition and Growth reactive flow model [11] uses two Jones-Wilkins-Lee (JWL) equations of state, one for the un-reacted explosive and another one for the reaction products, in the form:

$$p = Ae^{-R_1 V} + Be^{-R_2 V} + \omega C_V T/V \quad (1)$$

where p is pressure in Megabars, V is relative volume, T is temperature, ω is the Gruneisen coefficient, C_V is the average heat capacity, and A, B, R_1 and R_2 are constants. The equations of state are fitted to the available shock Hugoniot data. Table I contains the modeling parameters and reaction rate constants for these experiments. The reaction rate equation is:

$$dF/dt = \underbrace{I(1-F)^b(\rho/\rho_0 - 1 - a)^x}_{0<F<F_{Ig\max}} +$$

$$\underbrace{G_1(1-F)^c F^d p^y}_{0<F<F_{G1\max}} + \underbrace{G_2(1-F)^e F^g p^z}_{F_{G2\min}<F<1} \quad (2)$$

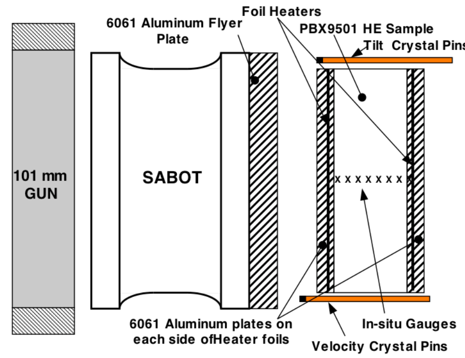

FIGURE 1. Typical description of a shock initiation experiment.

Table I. Ignition and Growth modeling parameters.

UNREACTED JWL	PRODUCT JWL
A=7320 Mbar	A=16.689 Mbar
B=-0.065278 Mbar	B=0.5969 Mbar
R_1=14.1	R_1=5.9
R_2=1.41	R_2=2.1
ω=0.8867	ω=0.450
C_V=2.7806x10^{-5} Mbar/K	C_V=1.0x10^{-5} Mbar/K
T_O = 423ºK	E_O=0.102 Mbar
Shear Modulus=0.0354 Mbar	-
Yield Strength=0.002 Mbar	-
ρ_0=1.762 g/cm^3	-
REACTION RATES	
a=0	x=4.0
b=0.667	y=1.0
c=0.667	z=2.0
d=0.277	F_{igmax}=0.3
e=0.333	F_{G1max}=0.5
g=1.0	F_{G2min} =0.5
I=1.4 x 10^{11} μs^{-1}	G_1=190 Mbar^{-2}μs^{-1}
-	G_2=400 Mbar^{-2}μs^{-1}

where F is the fraction reacted, t is time in μs, ρ is the current density in g/cm^3, ρ_O is the initial density, p is pressure in Mbars, and I, G_1, G_2, a, b, c, d, e, g, x, y, and z are constants. This reaction rate law models the three stages of reaction generally observed during shock initiation of solid explosives. Table II details the Gruneisen parameters used.

Table II. Gruneisen parameters for inert materials.

INERT	ρ_0 (g/cc)	C (km/s)	S_1	S_2	S_3	γ_0	a
6061-T6 Al	2.703	5.24	1.4	0.0	0.0	1.97	0.48
Teflon	2.15	1.68	1.123	3.98	-5.8	0.59	0.0

RESULTS/DISCUSSION

Table III contains the experimental flyer velocities, impact pressures, and run distances to detonation for the two PBX 9501 shots performed at 150°C.

Table III. PBX9501 gun experiments at 150°C.

SHOT	IMPACT VELOCITY	INPUT PRESSURE	RUN TO DET
4663	0.72 km/s	3.3 GPa	7.1 mm
4664	0.54 km/s	2.3 GPa	11.2 mm

The resulting data points are plotted on the Pop-plot as shown in Figure 2. The data from this work are plotted as filled circles and agree well with the previous data by LANL at 150°C [1] shown in the open circles. The other data from the same work are also plotted for reference to compare this data to other test temperatures.

The in-situ gauge records are shown in Figures 3 and 5 for experiments 4663 and 4664 respectively. An increase in pressure can be observed as the shock progresses through and reacts the explosive material until a full detonation is observed. Ignition and Growth reactive flow modeling results are shown in Figures 4 and 6 in the form of simulated gauge records. They simulate the experimental records in Figures 2 and 4 respectively. From comparing these records a good agreement can be seen.

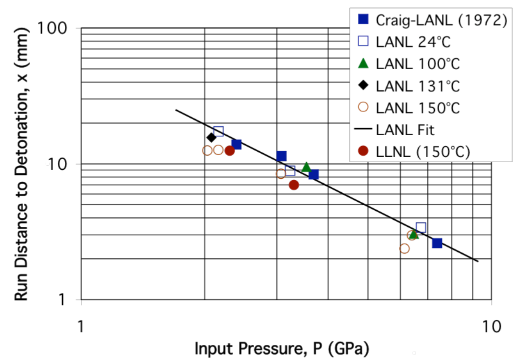

FIGURE 2. Pop-Plot comparing the data from this work with that of previous experiments.

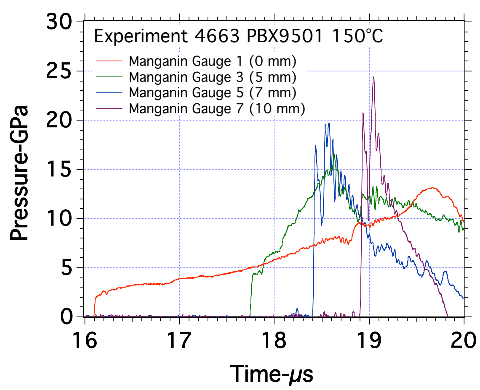

FIGURE 3. Experimental pressure histories for 150°C PBX 9501 impacted by an aluminum flyer plate at 720 m/s.

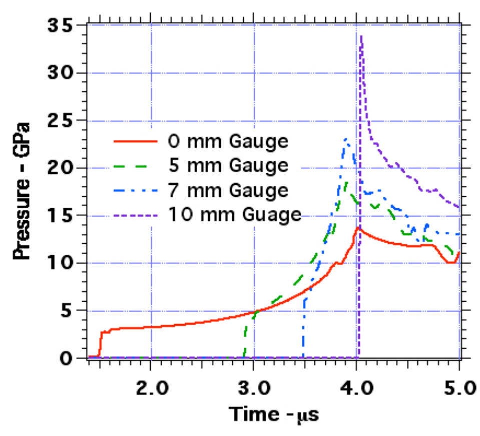

FIGURE 4. Calculated pressure histories for 150°C PBX 9501 impacted by an aluminum flyer plate at 720 m/s.

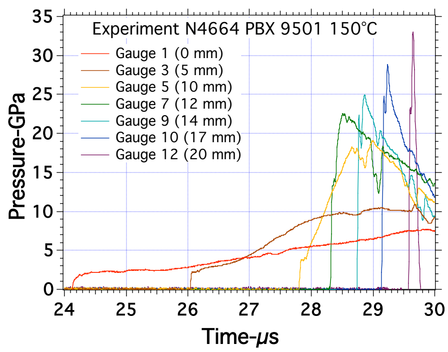

FIGURE 5. Experimental pressure histories for 150°C PBX 9501 impacted by an aluminum flyer plate at 540 m/s.

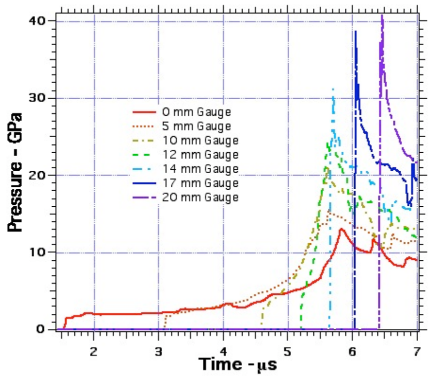

FIGURE 6. Calculated pressure histories for 150°C PBX 9501 impacted by an aluminum flyer plate at 540 m/s.

SUMMARY

Shock initiation experiments on the explosive PBX9501 (95% HMX, 2.5% estane, and 2.5% nitroplasticizer by weight) were performed at 150°C to obtain in-situ pressure gauge data and Ignition and Growth modeling parameters. The run-distance-to-detonation points on the Pop-plot for these experiments showed agreement with previously published data and Ignition and Growth modeling parameters were obtained with a good fit to the experimental data.

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