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MANGANIN GAUGE AND REACTIVE FLOW MODELING STUDY OF THE SHOCK INITIATION OF PBX 9501*

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A series of 101mm diameter gas gun experiments was fired using manganin pressure gauges embedded in the HMX-based explosive PBX 9501 at initial temperatures of 20°C and 50°C. Flyer plate impact velocities were chosen to produce impact pressure levels in PBX 9501 at which the growth of explosive reaction preceding detonation was measured on most of the gauges and detonation pressure profiles were recorded on some of the gauges placed deepest into the explosive targets. All measured pressure histories for initial temperatures of 25°C and 50°C were essentially identical. Measured run distances to detonation at several input shock pressures agreed with previous results. An existing ignition and growth reactive flow computer model for shock initiation and detonation of PBX 9501, which was developed based on LANL embedded particle velocity gauge data, was tested on these pressure gauge results. The agreement was excellent, indicating that the embedded pressure and particle velocity gauge techniques yielded consistent results.

INTRODUCTION

The relative safety of high energy materials based on octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX) is very important. PBX 9501, which contains 95 weight % HMX, 2.5 weight % estane binder, and 2.5 weight % BDNPA/F, is a widely used HMX-based plastic bonded explosive. Its shock sensitivity has previously been studied using embedded particle velocity gauges (1,2) and VISAR at low input shock pressures (3,4). In this paper, the shock sensitivity of PBX 9501 at 25°C and 50°C was measured using embedded manganin pressure gauges to determine whether particle velocity measurement techniques agreed with pressure measurement techniques. The experimental records were compared through the use of the Ignition and Growth reactive flow model for PBX 9501, which had been previously normalized to particle velocity gauge data in the same input shock pressure regime (3). If this PBX 9501 Ignition and Growth model can calculate manganin pressure gauge records accurately with no adjustments, then the two experimental techniques are producing equilvalent shock initiation data. Thus they can be used interchangeably or in combination.

EXPERIMENTAL

The experimental geometry for the PBX 9501 embedded gauge experiments is identical to those in previous studies (5-8). A 100mm diameter, 12.5 mm thick aluminum flyer plate impacts a target consisting of: a 90mm diameter, 6mm thick aluminum plate; a 90mm diameter, 20mm thick PBX 9501 charge; and a 90mm diameter, 6mm thick aluminum back plate. In the heated experiments, the heaters were placed within the aluminum plates, and the PBX 9501 was heated to approximately 50°C at a rate of 1.6°C/minute. A total of three shots were fired. One 25°C experiment was fired with an aluminum flyer velocity of 0.697 mm/µs producing a shock pressure of approximately 3.2 GPa. Two shots were fired at 50°C with aluminum flyer plate velocities of 0.649 and 0.8005 mm/µs, imparting pressures of 3.1 GPa and 4 GPa, respectively. An initial temperature of 50°C for PBX 9501 was used, because it is known that the shock sensitivity of HMX-based explosives increases for temperatures in the 150 – 170 °C regime (8), but no data was available in the 50°C range to which explosives may be subjected in hot climates and certain applications.

REACTIVE FLOW MODELING

The Ignition and Growth reactive flow model uses two Jones-Wilkins-Lee (JWL) equations of state, one for the unreacted explosive and another one for the reaction products, in the temperature dependent form:

$$p = A\, e^{-R_1 V} + B\, e^{-R_2 V} + \omega C_v T/V \qquad (1)$$

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 unreacted equation of state is fitted to the available shock Hugoniot data, and the product equation of state is fitted to cylinder test and other metal acceleration data. The reaction rate equation is:

$$dF/dt = \underset{0<F<F_{igmax}}{I(1-F)^b(\rho/\rho_0-1-a)^x} + \underset{0<F<F_{G1max}}{G_1(1-F)^c F^d p^y} + \underset{F_{G2min}<F<1}{G_2(1-F)^e F^g p^z} \qquad (2)$$

where F is the fraction reacted, t is time in μs, ρ is the current density in g/cm^3, ρ_0 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 three term reaction rate law models the three stages of reaction generally observed during shock initiation of pressed solid explosives (6). The equation of state parameters for PBX 9501, aluminum, and Teflon, and the Ignition and Growth rate law parameters for PBX 9501 are listed in Table 1. These parameters were previously normalized to several particle velocity gauge experiments fired at Los Alamos National Laboratory. Sheffield et al. (1) did a careful study of the effect of initial density on the shock sensitivity of new and aged PBX 9501. The average density of the three PBX 9501 charges used in this study was 1.838 g/cm^3. A change in temperature from 25°C to 50°C does not change the density significantly. The only change in the 50°C PBX 9501 parameters from the ambient parameters is a lower B value in the unreacted JWL equation of state so that p=0 at V=1 and T_o = 323°K.

TABLE 1. Equation of State and Reaction Rate Parameters

1. Ignition and Growth Model Parameters for PBX 9501

T_o=298°K; ρ_0 =1.838 g/cm^3; Shear Modulus=0.0354 Mbar; Yield Strength=0.002 Mbar

Unreacted JWL	Product JWL	Reaction Rate Parameters	
A=7320 Mbar	A=16.689 Mbar	I=1.4e+11	G_2=400
B=-0.052654 Mbar	B=0.5969 Mbar	a=0.0	e=0.333
R_1=14.1	R_1=5.9	b=0.667	g=1.0
R_2=1.41	R_2=2.1	x=20.0	z=2.0
ω=0.8867	ω=0.45	G_1=130	F_{igmax} = 0.3
C_V=2.7806e-5 Mbar/°K	C_V=1.0e-5 Mbar/°K	y=2.0	F_{G1max}=0.5
	E_0=0.095 Mbar	c=0.667, d=0.277	F_{G2min}=0.5

To=50°C=323°K B=-0.055179 Mbar

2. Gruneisen Parameters for Inert Materials

$$p = \rho_0 c^2 \mu[1+(1-\gamma_0/2)\mu - a/2\mu^2] \,/\, [1-(S_1-1)\mu - S_2\mu^2/(\mu+1) - S_3\mu^3/(\mu+1)^2]^2 + (\gamma_o + a\mu)E$$

where $\mu=(\rho/\rho_0)-1$ and E is thermal energy

Inert	ρ_0(g/cm^3)	c(mm/μs)	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

TABLE 2. Experimental flyer velocities, impact pressures, and run distances to detonation

Flyer Velocity (mm/μs)	Impact Pressure (GPa)	PBX 9501 Temperature (°C)	Experimental Run to Detonation Results Distance(mm)	Time(μs)
0.697	3.4	25	11	3.4
0.649	3.0	50	13	4.3
0.8005	4.0	50	8	2.4

EXPERIMENTAL RESULTS

Table 2 contains the experimental flyer velocities, impact pressures, and run distances to detonation for the three PBX 9501 shots. Figure 1 shows the measured pressure histories at the six gauge locations (0,5,7,9,12, and 15mm) in PBX 9501 at 25°C impacted by an aluminum flyer plate at 0.697 mm/μs. The gauge records and calculations show that this input shock pressure of 3.2 GPa causes detonation to occur just before the 12mm gauge depth. Two other comparisons for 50°C PBX 9501 are shown in Figs. 2 and 3. Figure 2 contains six gauge records at 0,5,10,12,14, and 17mm for the 0.649 mm/μs aluminum flyer impact velocity experiment. The transition to detonation occurs between 12 and 14 mm. Figure 3 contains the manganin gauge records at four depths (0,3,7, and 10mm) for the 50°C PBX 9501 shot which had an aluminum flyer velocity of 0.8005 mm/ms. The transition to detonation occurred just beyond the 7 mm deep gauge. For all three experiments, the run distances and times to detonation agree well with those measured by Sheffield et al. (1,2).

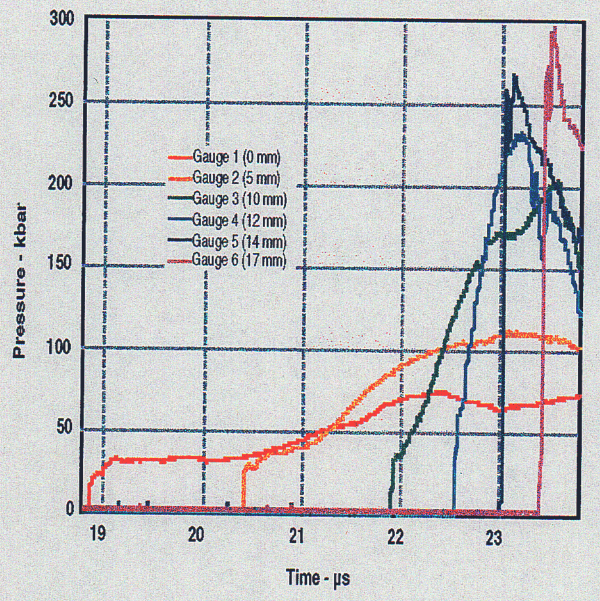

FIGURE 2. Pressure histories for 50°C PBX 9501 shock initiated by an aluminum flyer at 0.649 mm/μs

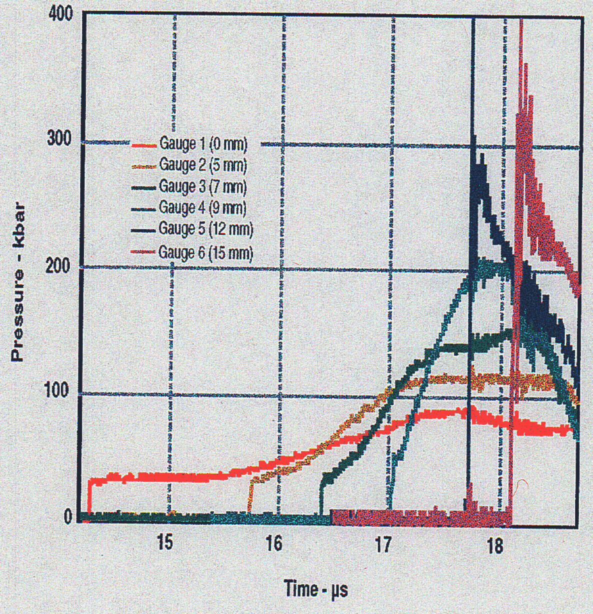

FIGURE 1. Pressure histories for 25°C PBX 9501shock initiated by an aluminum flyer at 0.697 mm/μs

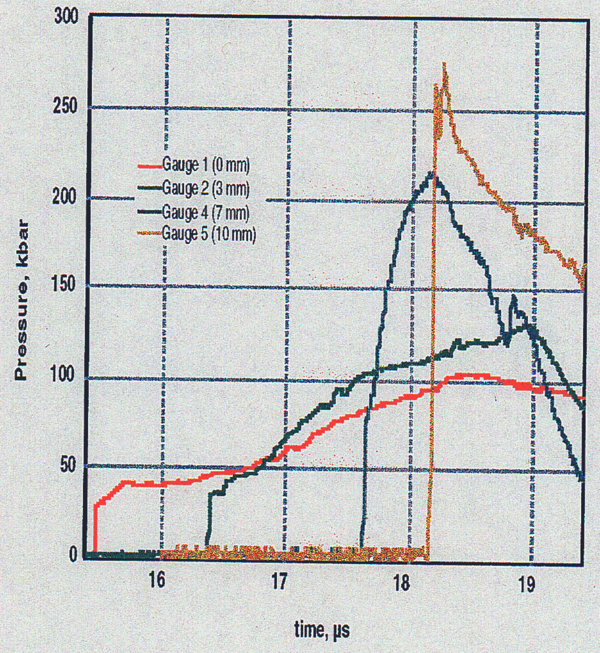

FIGURE 3. Pressure histories for 50°C PBX 9501 shock initiated by an aluminum flyer at 0.8005 mm/μs

MODELING RESULTS

The Ignition and Growth reactive flow modeling results for the three PBX 9501 experiments in Figs. 1 – 3 are shown in Figs. 4 – 6, respectively. Ignition and Growth reactive flow modeling shows that manganin pressure gauges are yielding equivalent results to particle velocity gauges.

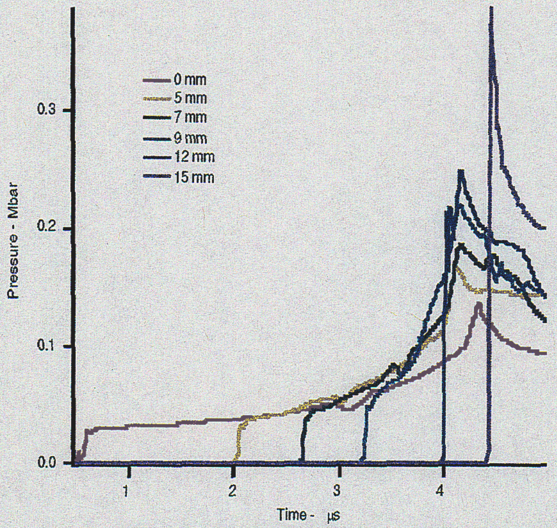

Figure 4. Calculated pressure histories for 25°C PBX 9501 impacted by an aluminum flyer at 0.697 mm/µs

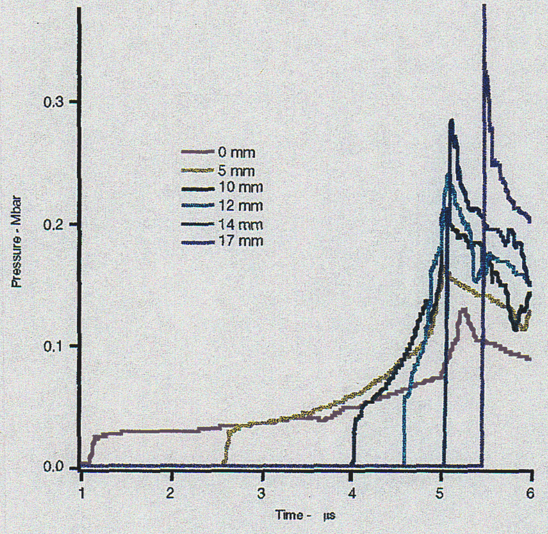

Figure 5. Calculated pressure histories for 50°C PBX 9501 impacted by an aluminum flyer at 0.649 mm/µs

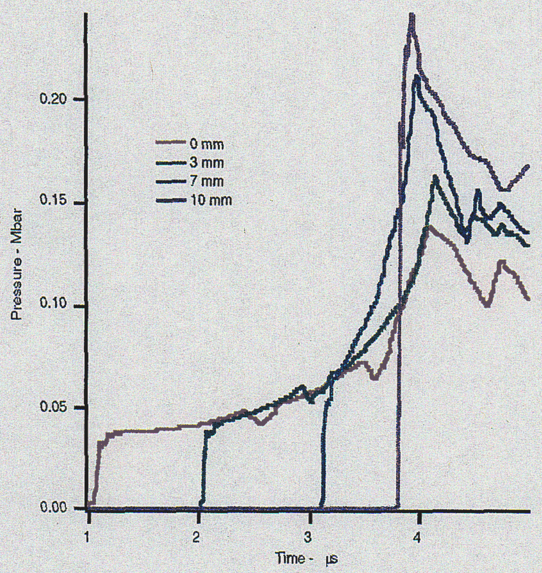

Figure 6. Calculated pressure histories for 50°C PBX 9501 impacted by an aluminum flyer at 0.8005 mm/µs

ACKNOWLEDGMENTS

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