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Lagrange Method Investigation Used for Shock Wave Extinguished in Small Partition Assay Experiment

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Abstract: In order to investigate the characters of high energy solid explosives initiated by shock waves, the Lagrange analytical experiment equipment was designed. The effects on the shock sensitivity of pressed TNT were quantitatively measured. Ignition and Growth reactive flow models for the pressed TNT were formulated based on the measured pressure histories. The shock wave extinguished in pressed TNT was experimentally investigated and analyzed by Lagrange method in the case of small partition assay. The reaction rate obtained by Lagrange method indicates that there are partly reactions when the shock wave extinguished in the solid explosives.

Keywords: Lagrangian analysis, shock wave, solid explosive, state equation

INTRODUCTION

With safety of solid high explosives shocked initiation. Hazard scenarios can involve multiple stimuli, such as flyer plates accelerated impact explosives, producing strong shock waves in explosive or decay to a deflagration wave or to a non-reacting wave. So the study of property of energetic materials is important to gain knowledge if a material will detonate or not.

The reactive flow model for simulating shock initiation of energetic materials has been in use since the early 1980. The model is based on an ignition and growth of reaction rate equation for modeling high explosives as they transition from the unreacted state to the reacted state. A JWL form of Equation of State (EOS) is used to describe the response of the reacted (explosive products). An equation of state, typically JWL form, is also used to describe the response of the unreacted (inert) material. The reaction rate equation is used to determine the amount of the material that reacts every cycle (fraction reacted) and the transition from the unreacted to the reacted state.

Previous research (Tarver *et al*., 1997, 1985; Urtiew *et al*., 1989; Bahl *et al*., 1985; Urtiew *et al*., 1996, 1997; Green *et al*., 1989.) using unconfined and weakly confined charges of LX-04-01 and LX-17 showed that the increase in shock sensitivity was primarily due to two effects: the increase in the number and size of reacting hot spots formed by shock compression and the increase in hot spot growth rate into the surrounding explosive particles. The side effects always decrease the shock waves especially for the shocking initiation with small size. The previous research are almost study the shock initiation while the shock wave extinguished in the solid explosives had not investigated.

The research using unconfined charges of pressed TNT with small size used for the investigation of the shock wave extinguished in the pressed TNT had been carried out in this study.

EXPERIMENTS

Shock initiation experiments have been carried out for Pressed TNT. Our goal is to investigated the shock wave extinguished in the pressed TNT. The schematic diagram of experimental is shown in Fig. 1.

The Π type of manganin-constantan composite 2-D Lagrange sensors are used in the experiments (Fig. 2). Fabricate process of multilayer integrate circuit is adopted on the sensors, precision of superposition between cornwall foil and mangan in foil is less than 0.005 mm.

The signals can be obtained by the oscillograph which changed to the pressure by using the formula:

$$P = 0.27 + 34.4\frac{\Delta R}{R_0} + 1.70(\frac{\Delta R}{R_0})^2 \quad (1)$$

where, P is the pressure, ΔR is the chang of the resistance, R_0 is the initial resistance. The histories of $p-$-time experimented is shown in Fig. 3.

Lagrangian method: Conservation equations in two-dimensions as follows (Clutter and Belk, 2002.):

$$u = u_1 - \frac{1}{\rho}\int_{t1}^{t2}(\frac{l}{l_0})^2(\frac{\partial P}{\partial h})_t dt \quad (2)$$

$$v = v_1 + \int_{t1}^{t2}(\frac{l}{l_0})^2(\frac{\partial u}{\partial h})_t dt \quad (3)$$

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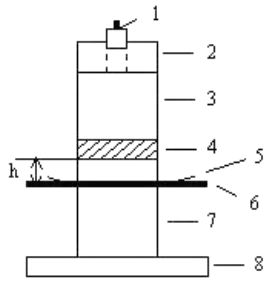

Fig. 1: Experimental set-up for small scale gap test 1: Detonator; 2: Detonator holder; 3: Detonator explosive charge 4 Copper; 5: Gauge; 7: TNT; 8: Witness plate

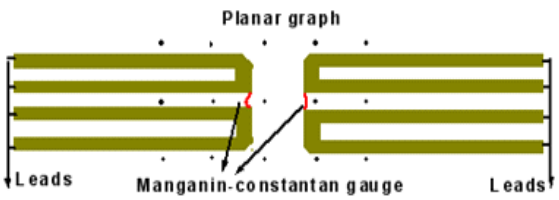

Fig. 2: Π type of manganin-constantan composite 2-D Lagrange sensor measured for 2-D axial-symmetric high pressure flow field

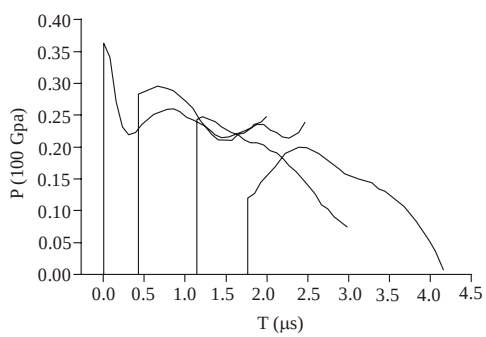

Fig. 3: Histories of *p*-time experimented

$$E = E_1 - \int_{t1}^{t2} P(t)(\frac{\partial v}{\partial t})_h dt \quad (4)$$

where P_0 is the density, u is particle velocity, u_1 is particle velocity of shock front, v is relatively specific volume, v_1 is relatively specific volume of shock front, E is internal energy per unit volume, E_1 is internal energy per unit volume of shock front, and t_1, t_2 is start time and end time, respectively. h is Lagrangian position, l is radial displacement, l_0 is the length of sensitive part, l/l_0 is relatively radial displacement.

The path and trace lines are adopted to prevent the useful information lost in integral along the isochrone lines. The analogical points[5](the characteristic points on the waves such as the end point of elastic wave, the peak point of plastic wave etc.) in the pressure-time curves are connected to establish the path lines.

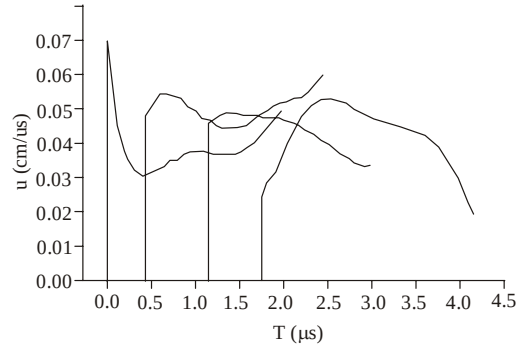

Fig. 4: Histories of *u*-time calculated

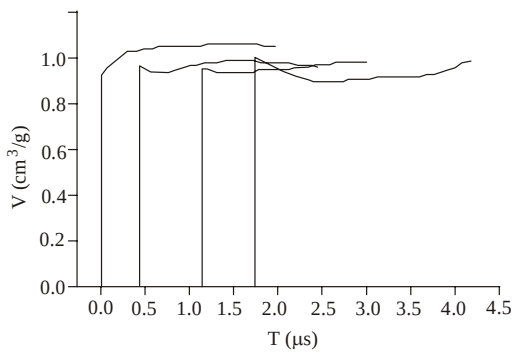

Fig. 5: Histories of *v* -time calculated

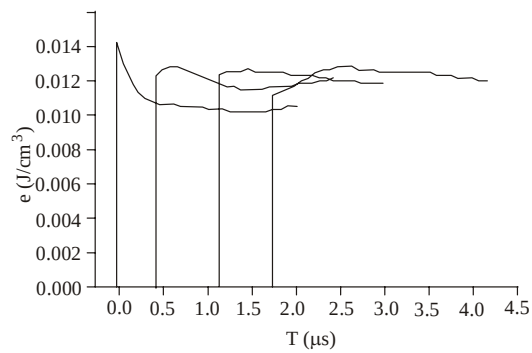

Fig. 6: Histories of *e* -time calculated

On the assumption, The tested TNT and the lagrange gauges move with the same speeds because of the lagrange gauges are in the tested TNT. The trace lines are the curves of the parameters varied with the time recorded by the lagrange gauges.

The integral along isochrone lines can be changed along the path lines and particle lines:

$$(\frac{\partial p}{\partial h})_t (\frac{dp}{dh})_j - (\frac{\partial p}{\partial t})_h (\frac{dt}{dh})_j \quad (5)$$

$$(\frac{\partial u}{\partial h})_t(\frac{du}{dh})_j - (\frac{\partial u}{\partial t})_h(\frac{dt}{dh})_j \quad (6)$$

So, the Eq. (2), (3) and (4) can be written as follows:

$$u = u_1 - \frac{1}{\rho_0}\int_{t_1}^{t_2}(\frac{l}{l_0})^2[(\frac{\partial P}{\partial h})_j - (\frac{\partial P}{\partial t})_h(\frac{\partial P}{\partial h})_j]dt \quad (7)$$

$$v = v_1 + \int_{t_1}^{t_2}(\frac{l}{l_0})^2[(\frac{\partial u}{\partial h})_j - (\frac{\partial u}{\partial t})_h(\frac{\partial t}{\partial h})_j]dt \quad (8)$$

$$E = E_1 - \int_{t_1}^{t_2} P(t)(\frac{\partial v}{\partial t})_h dt \quad (9)$$

Theu (t),v(t) and e(t) curves are all obtained from the Eq. (2), (3) and (4) with the integral along the path and trace lines of p(t) curves (Fig. 4, 5, 6). The integral along isochrone lines changed to along the path and trace lines with no other suppose with the Eq. (5) and (6). The error are mainly from the experiment and the curves fitting. The least square curves fitting method is adopted with B spline function as test function to prevent the error diffusing to the whole flow field.

Single-temperature model: There are two mixture model which can be used. Firstly, we can suppose the volume between the reacted explosive and the unreacted explosive are equal. The other is the single-temperature model which suppose the pressure between the reacted explosive and the unreacted explosive are equal. Here, The single-temperature models as mixture laws used in the shock initiation which assumed that the pressures and temperatures between the reacted explosives and un-reacted explosives are equal. The reaction rate. And the relative specific volumes are additive, i.e.,

$$P_m = P_s = P_g \quad (10)$$

$$T_m = T_s = T_g \quad (11)$$

$$V_m = (1 - F)v_s + Fv_g \quad (12)$$

$$e_m = (1 - F)e_s + Fe_g \quad (13)$$

where subscript m is the mixed state, subscript s is the un-reacted state, subscript g is the reacted state, F is the reaction rate.

State equation: The model uses two Jones-Wilkins-Lee (JWL) equations of state, one for the un-reacted explosive and one for its reaction products, in the temperature dependent form Kury *et al*. (1999), Huan and Ding (1989), (1990) and Gaupta (2003):

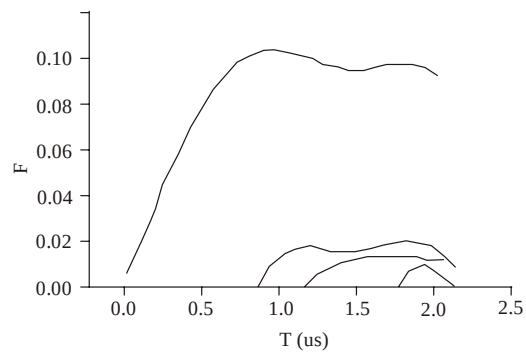

Fig. 7: Histories of F-time calculated

$$P = Ae^{-R_1V} + B_e^{-R_2V} + \frac{\omega C_V T}{V} \quad (14)$$

A JWL equation of state defines the pressure in the un-reacted explosive as:

$$P_e = A_e e^{-R_1V_e} + B_e e^{-R_2Ve} + \frac{\omega_e C_{Ve} T_e}{V_e} \quad (15)$$

where, P_e is the pressure, V_e and T_e are the relative volume and temperature, respectively, of the un-reacted explosive, A_e, B_e, R_1, R_2 are constants, C_{ve} is average heat capacity of un-reacted high explosive, ω_e is Gruneisen coefficient.

Another JWL equation of state defines the pressure in the reaction products as:

$$P_p = A_p e^{-R_3V_p} + B_p e^{-R_2Vp} + \frac{\omega_p C_{Vp} T_p}{V_p} \quad (16)$$

where, P_p is pressure in Megabars, V_p and T_p are the relative volume and temperature, respectively, of the un-reacted explosive, A_p, B_p, R_3, R_4 are constants, C_{vp} is average heat capacity of reaction products, ω_p is Gruneisen coefficient.

Simultaneous Eq. (10)-(13), (15) and (16), the reaction rate histories can be calculated which can used to determine the parameters of the Ignition and Growth models. The reaction rate histories are shown in Fig. 7.

The Ignition and Growth reactive flow of shock initiation and detonation of solid explosives has been incorporated into several hydro dynamic computer codes and used to solve many explosive and propellant safety and performance problems.

$$\frac{DF}{Dt} = (I - F)^b(\frac{\rho}{\rho_0} - 1 - a)^x + G_1(I - F)^c F^d P^y + G_2(1 - F)^e F^g P^z \quad (17)$$

Table 1: Ignition and growth parameters for pressed TNT

Unreacted JWL	Product JWL
A = 17.98 Mbar	A = 3.712 Mba
B = -0.9310 Mbar	B = 0.03231 Mbar
R_1 = 6.2	R_1 = 4.15
R_2 = 3.1	R_2 = 0.95
ω = 0.8926	ω = 0.3
C_v = 2.1e-5 Mbar/K	C_v = 1.0e-5 Mbar/K
T_0 = 298 K	E0 = 0.07 Mbar
Shear modulus = 0.04 Mbar	-
Yield strength = 0.002 Mbar	-
Reaction rates	
a = 0.065	x = 6
b = 0.667	y = 1
c = 0.667	z = 3
d = 0.667	F_{igmax} = 0.015
e = 0.333	F_{grmax} = 1.0
g = 0.333	F_{grmin} = 0.0
I = 8e8μ/s	G1 = 11.2/Mbarμ/s
-	G2 = 820/Mbarμ/s

where, F is the fraction reacted, t is time, ρ is the current density, ρ_0 is the initial density, and I, G1, G2, a, b, c, d, e, g, x, y and z are constants. Similarly to our previous study of shock initiation (Guoping *et al*., 2011), the model parameters for pressed TNT are listed in Table 1.

CONCLUSION

- The characters of the shock wave extinguished in pressed TNT was analyzed by Lagrange method in the case of small partition assay. The state equations of explosive and reaction products are all based on JWL state equations.The value-time relations of *u,v,e* on every Lagrange position are obtained.
- The reaction rate of the shock wave extinguished in pressed TNT was obtained. The results is that there are also partly reaction in the pressed TNT.
- The reaction rate was so small. Though we can use it to determine the growth and ignition model also, the errors are increasing on this condition.

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