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Ignition and growth modeling of plane wave shock initiation experiments on ultrafine Hexanitrostilbene (HNS-IV)

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ЗНЧ | ЗАБАБАХИНСКИЕ НАУЧНЫЕ ЧТЕНИЯ
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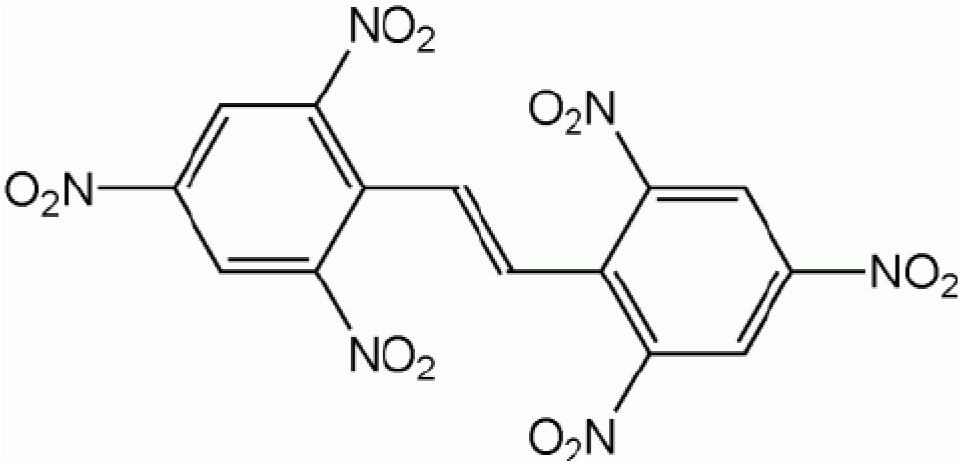
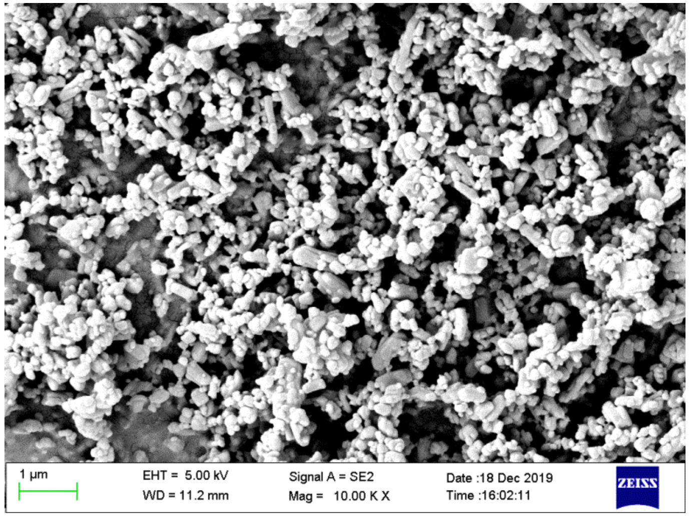
Introduction

- Hexanitrostilbene (HNS) is a heat-resistant booster explosive that is used in space missions and initiators, especially in slapper detonators, where explosives are impacted by thin flyer plates. HNS has been produced in several forms (I-V) with various particle sizes and purities. HNS-IV is crash precipitated from HNS-II, which was recrystallized from HNS-I. The crystal density of HNS is 1.74 g/cm^3, while it is generally used at density of around 1.60 g/cm^3, which implies a porosity of 8%. In order to improve the shaping performance of HNS, binders are added to form formulations such as LX-15 (95% HNS I and 5% Kel F-800).





SEM image of HNS-IV

T. W. Stull. Formulation of custom sized LX-15 granules. US: MHSMP-80-19, 1980.

Introduction

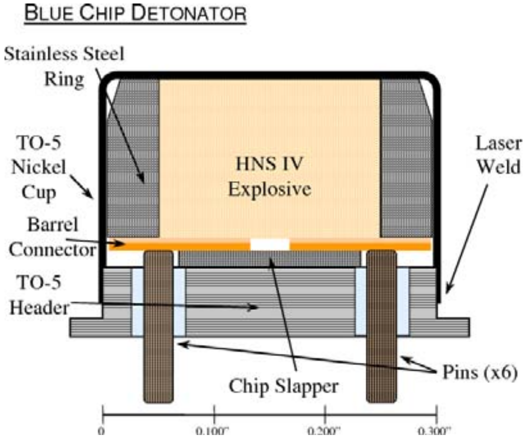
- The shock initiation of solid explosives has been discussed by Campbell et al. In order to study the shock initiation process of solid explosives, plane wave lens, projectile, rod, flyer plate and etc. have been used in experiments. In the parametric study of shock initiation, the light output in wedge test, particle velocity and pressure between explosive slabs are usually measured by high-speed rotating camera, electromagnetic particle velocimetry and manganin pressure gauges. Recently, the Doppler velocimetry has been widely used in detonation and shock wave measurements, where microwaves, laser, terahertz waves are commonly used.


Bullet just prior to impact

At bullet impact

5 seconds after bullet impact

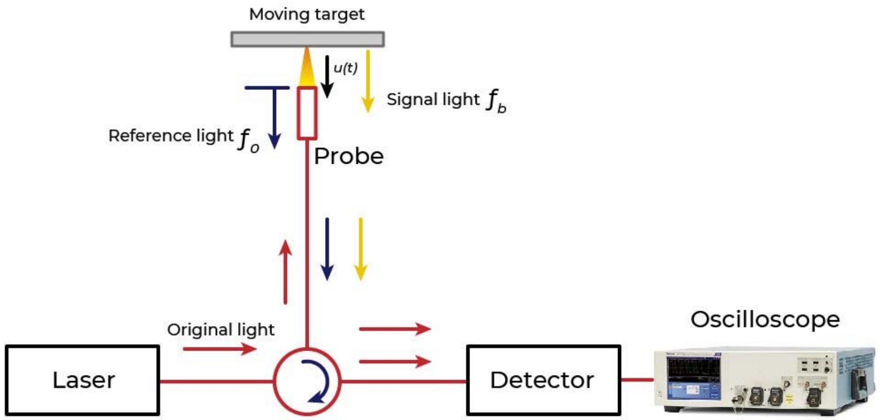
Bullet test



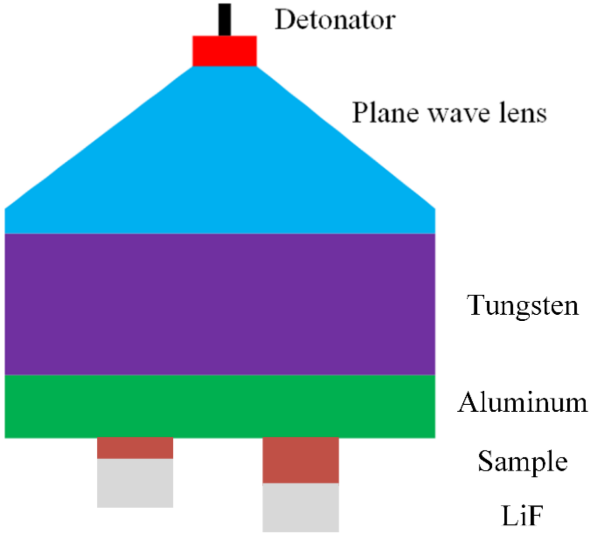
A. W. Campbell, W. C. Davis, J. B. Ramsay, J. R. Travis, Shock initiation of solid explosives, Phys. Fluids 1961, 4, 511-521

Introduction

- In this work, the interface velocity between sample charge and LiF window was measured by photonic Doppler velocimetry, to investigate the plane wave shock initiation of HNS-IV based explosive (97.5% HNS-IV and 2.5% binder, ρ_0 = 1.58 g/cm^3).
- Simultaneously, the equations of state of unreacted explosive and detonation products were obtained from gas gun experiment and Φ 10 mm cylinder expansion test.



Schematic of photonic Doppler velocimetry



Schematic of plane wave initiation

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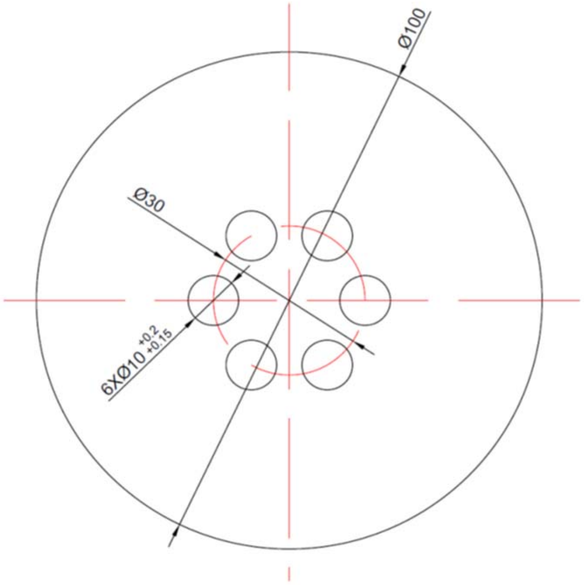
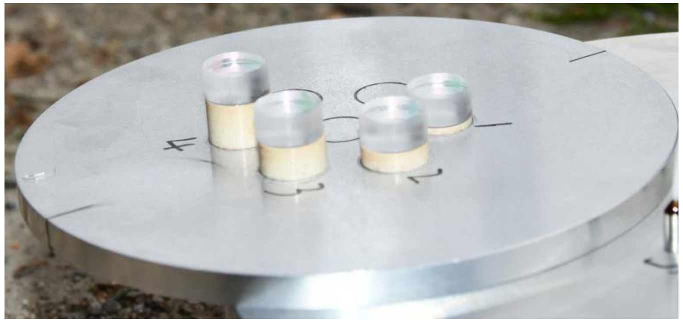
Experimental

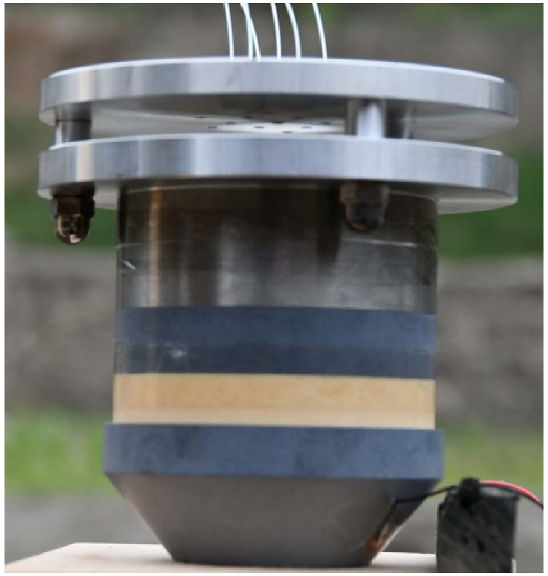
- The Φ100 plane wave lens and Φ100×20 HMX-based explosive (95% HMX and 5% binder, $\rho_0 = 1.857 \pm 0.002\ \mathrm{g/cm^3}$) were used to produce plane shock wave, which was attenuated by tungsten (W95NiFe) and aluminum (2A12) plates. Then the Φ10 sample charges were attached to the aluminum attenuator plate. In order to obtain more data in one shot, up to six sample charges with varying thicknesses could be mounted simultaneously, which were evenly distributed along the Φ30 circumference.





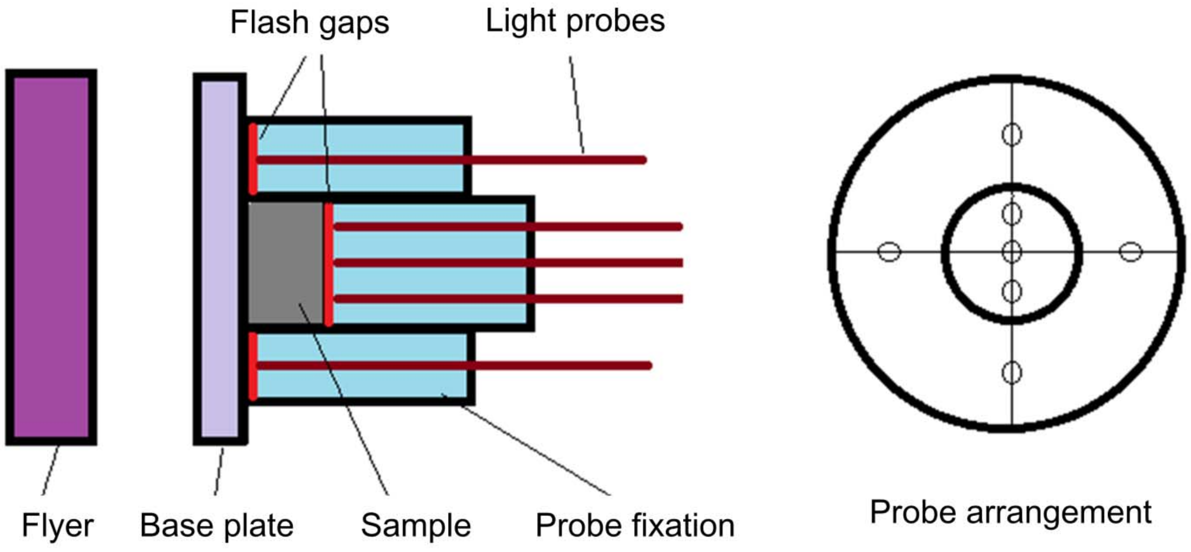
Experimental

- Four charges with thicknesses of 1, 3, 5, 7 mm were mounted to aluminum plate, and the other two locations could be used for free surface velocity measurement. The Φ10×5 LiF window was mounted to the other end of sample charge. A 0.6-μm-thick aluminum foil was deposited on the window face next to the explosive to provide a reflective surface. The aluminum layer is thin enough and has a shock impedance close to that of LiF window to introduce negligible perturbations into the interface velocity histories.
- By changing the thickness of attenuators, different amplitudes of shock waves could be obtained.



Experimental

- The unreacted Hugoniot relationship was obtained from gas gun launching flyer impact experiment. While the detonation products state was obtained from Φ 10 mm cylinder expansion test.



Probe arrangement

Gas gun launching flyer impact experiment

Cylinder test

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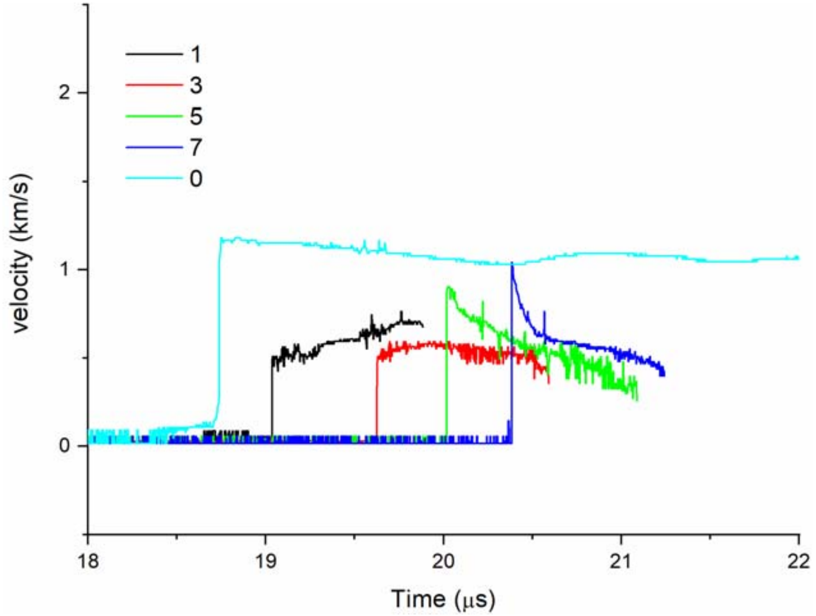
Results and Discussion

- The typical free surface velocity of aluminum plate and true interface velocity between sample charge and LiF window were shown below. The free surface velocity could be used to calculate the output pressure of shock wave. The obtained apparent interface velocity histories should be corrected for the index of refraction of LiF to generate true interface velocity histories.



Experimental results

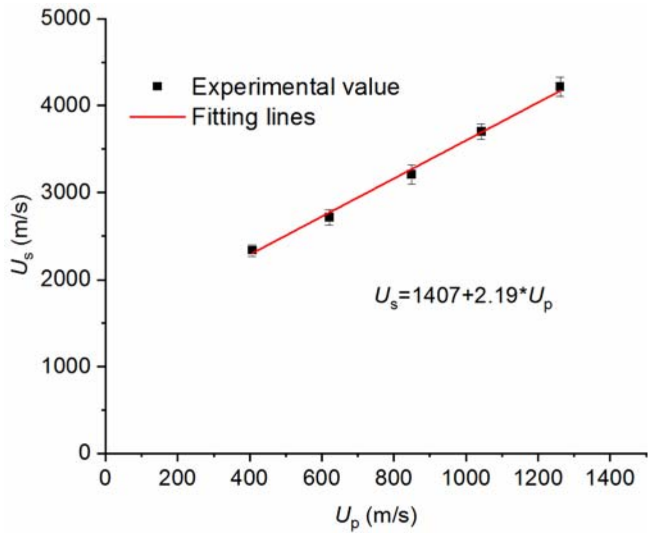
Q. Liu, X. Zhou, X. Zeng, S. N. Luo, Sound velocity, equation of state, temperature and melting of LiF single crystals under shock compression, *J. Appl. Phys.* **2015**, *117*, 045901.

Results and Discussion

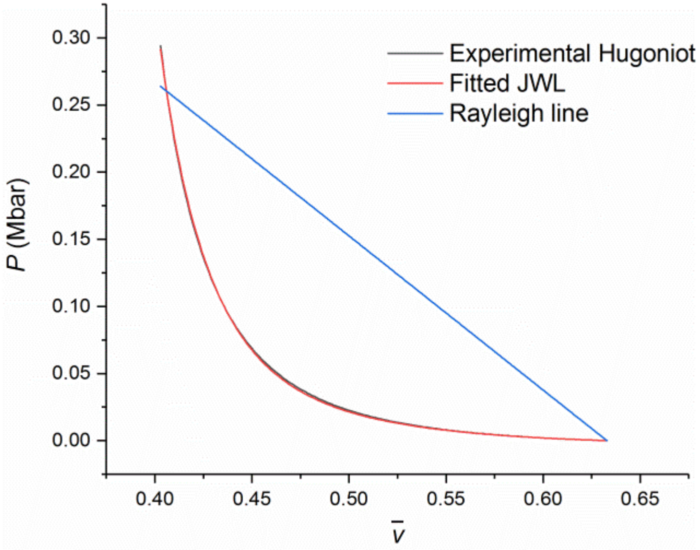
- The ignition and growth reactive flow model uses two Jones-Wilkins-Lee (JWL) equations of state (EOS’s), one for unreacted explosive and one for reaction products:

$$p = A\mathrm{e}^{(-R_1\bar{v})} + B\mathrm{e}^{(-R_2\bar{v})} + \omega C_{\mathrm{v}} T / \bar{v} \qquad (1)$$

where p is pressure, $\bar{v}$ is relative volume, T is temperature, ω is the Grüneisen coefficient, C_V is the average heat capacity, and A, B, R_1 and R_2 are constants. These EOS’s are fitted to unreacted Hugoniot and reaction product expansion data. The genetic algorithm was used in the fitting.



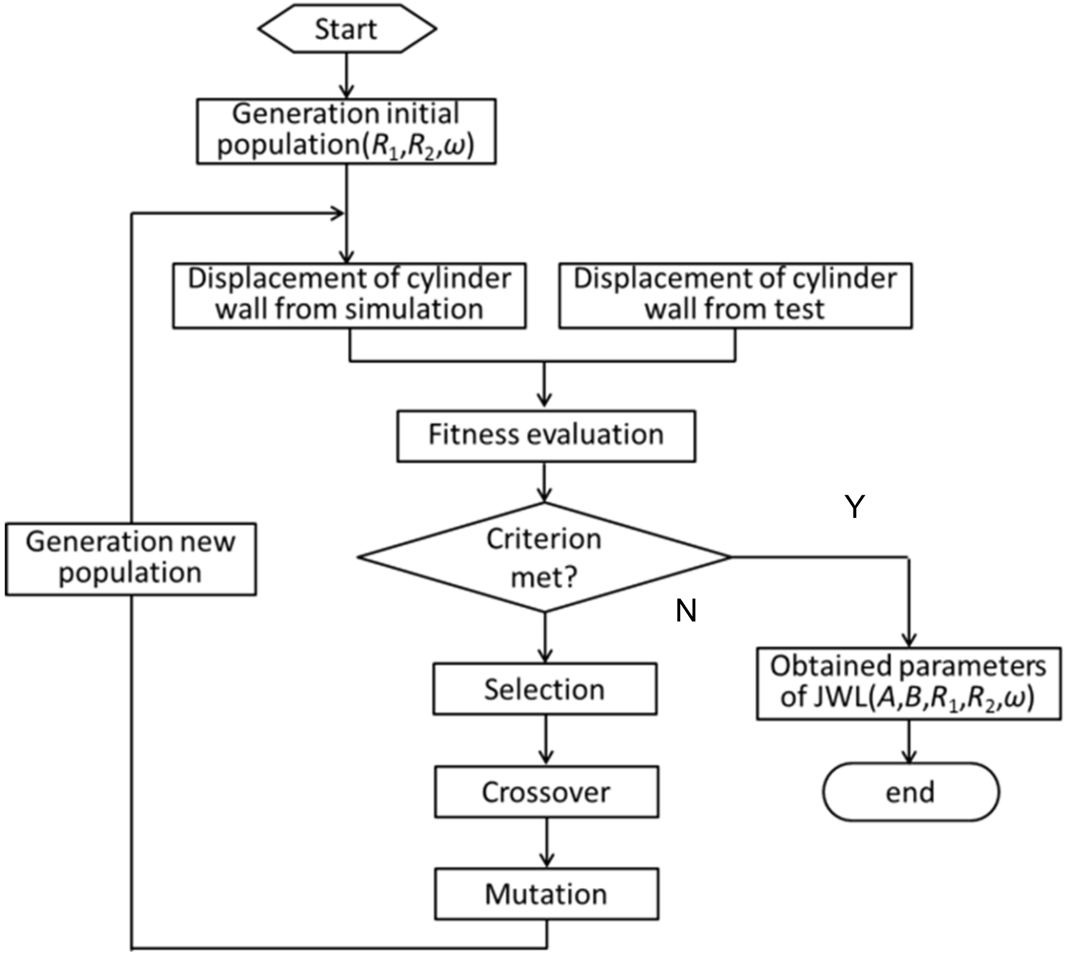
Relationship between shock velocity U_s and particle velocity U_p



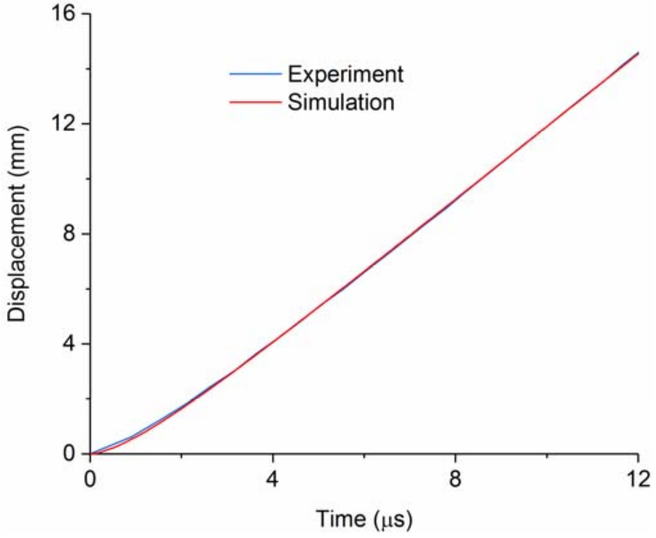
Fitting JWL EOS to unreacted Hugoniot

Results and Discussion

$$P = A\left(1-\frac{\omega}{R_1\bar{v}}\right)e^{-R_1\bar{v}} + B\left(1-\frac{\omega}{R_2\bar{v}}\right)e^{-R_2\bar{v}} + \frac{\omega E_0}{\bar{v}}$$



Genetic algorithm flow chart for solving JWL detonation products EOS



Cylinder displacement

Results and Discussion

- The three-term reaction rate equation is used:

$$\mathrm{d}F/\mathrm{d}t = I(1-F)^{b}(\rho/\rho_0 - 1 - a)^{x} + G_1(1-F)^{c}F^{d}p^{y} + G_2(1-F)^{e}F^{g}p^{z} \tag{2}$$

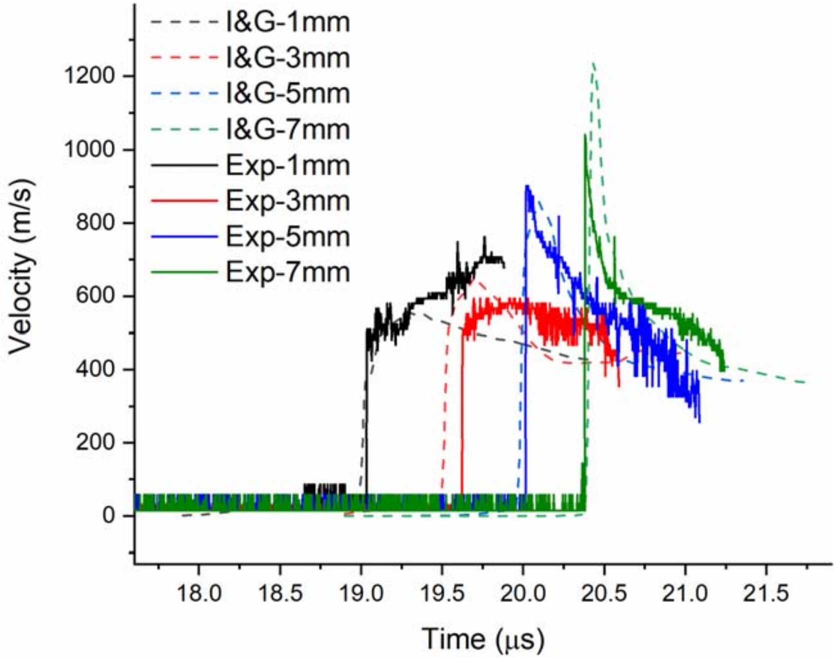
$$0 < F < F_{\mathrm{igmax}} \qquad 0 < F < F_{\mathrm{G1max}} \qquad F_{\mathrm{G2min}} < F < 1$$

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, and p is pressure in Mbars. I, G_1, G_2, a, b, c, d, e, g, x, y, z, F_{igmax}, F_{G1max} and F_{G2min} are constants. Pressure and temperature equilibration between the two phases of unreacted and reacted explosive are assumed. 15 parameters need to be fitted, fortunately, some parameters have empirical values that could reduce the workload.

E. L. Lee and C. M. Tarver, Phenomenological Model of Shock Initiation in Heterogeneous Explosives, Phys. Fluids 1980, 23, 2362

Results and Discussion

- Together with the unreacted JWL EOS and the product JWL EOS, the reaction rate parameters are compared to the experimental results. The simulation was conducted as 1-dimensional issue, which ignores the rarefaction from side. The comparison shows the agreement between the experimental and calculated interface particle velocity. All the parameters are given in Table followed.



Comparison between experimental and calculated data

Results and Discussion

Ignition and growth model parameters for HNS-IV/binder = 97.5/2.5 with density = 1.58 g/cm^3

Unreacted JWL EOS	Product JWL EOS	Reaction rate parameters
A = 8090 Mbar	A = 3.306 Mbar	A = 1.4e+6 μs^{-1} x = 8.0
B = -0.01522 Mbar	B = 0.1251 Mbar	b = 0.667 F_{G1max} = 0.3
R_1 = 16.55	R_1 = 4.324	a = 0.05 G_2 = 2000 $Mbar^{-3} \cdot \mu s^{-1}$
R_2 = 1.655	R_2 = 1.289	y = 2.0 z = 3.0
ω = 0.5226	ω = 0.2775	F_{igmax} = 0.08
C_V = 2.704e-5 $Mbar \cdot K^{-1}$	C_V =1.0e-5 $Mbar \cdot K^{-1}$	G_1 = 600 $Mbar^{-2} \cdot \mu s^{-1}$ F_{G2min} = 0.8
T_0 = 298K	E_0 =0.060 Mbar	c = d = e = g = 0.667

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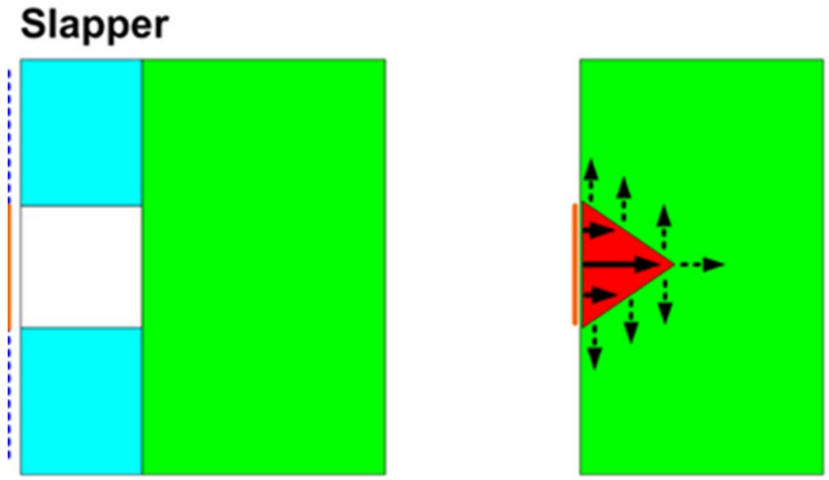
Conclusion

- The ignition and growth modeling of plane wave shock initiation on HNS-IV was obtained. The JWL equations of state of unreacted and detonation products of HNS-IV were fitted to experiments via genetic algorithm first , then the ignition and growth model parameters were fitted artificially.
- Further experimental and modeling efforts are required to explain the shock initiation of detonation by very thin, very high velocity and small diameter flyer plates. Which need flyer impact initiation experiments and three-dimensional modeling.



Thanks for your attention!

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