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Numerical simulation investigation on propagation of the detonation wave for small-charge

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Abstract

In order to study the effect of charge diameter and confinement on small-diameter detonation pressure, which the detonation pressure in different condition is studied by means of numerical simulation and experimental investigation. The results indicate that is enlarged with charge diameter enlarge under the same charge. And detonation pressure of 45# steel is bigger than PMMA. The effect of constraint condition are bigger when the charge diameter is little 3mm. The charge of 45# steel is superior in the axial detonation propagation. The conclusion indicated that the numerical simulation results are in accordance with experiments. And the detonation pressures of smaller charge were simulated.

Keywords: *charge diameter, confinement, detonation pressure, numerical simulation.*

1. Introduction

Theory research, experimental research and numerical simulation are three basic methods on explosion mechanics in modern times. The experimental method is dangerous in operation and its equipment is long price. The experimental collected data is very poor because of some technical problem. Only using simplified experimental research has more bigger limitation. Utilizing numerical simulation basic on experiment is a very useful method. A large number of financial resources, material resources and human resources can be saved. The numerical simulation results is more and overall than experimental data that is benefit to profound understand of propagating to the detonation wave in small charge. The intercoupling of hydromechanics and chemical reaction kinetics nonlinear partial differential equation can be resolved in suitable method of detonation numerical simulation of. t is basic on theory and experiment. In certain fields detonation behavior can be more deeply and fineness uderstanded444 than in theory and experiment.

In 1982, shock sensitivity experiments was simulated on 2DE program by Huang and Arbuckle[1] in US Army arms research office. In 1994, shock initiation experiments on B explosives was simulated on DYNA2D program by Murply and Lee[2] in Los Alamos National Laboratory. In 1982, Level Set was used to DSD by Aslam and Bdzil[3]. A numerical calculated method of using arbitrary complex 2D boundary condition was developed on propagation of detonation wave. In 2003, detonation process of shaped high explosive charge was simulated and analyzed in SPH program by M.B. Liu etal[4]. In 2004, PBXN-111 booster detonation process of corner effect was simulated in LS-DYNA by J.P.Lu and F.C.Christo1[5], picture and data of corner process were gained.

In 1999, the propagation on non-ideal detonation of IHE was simulated by Xu Zhang [6]. In 1999, shock initiation and detonation propagation were simulated in one dimension by Zhenyu Zhang [7].

In 1982, the nonlinear finite element code was used to calculate and analysis the dimensional effect of shock to detonation of JO-9159 by Changgen Feng [8].

In 1982, the blast effect was researched on numerical simulation and experimental investigation by Bin Liang [9].
The small charge detonation propagation was numerical simulated by LS-DYNA program. The conclusion indicated that the numerical simulation results was compare with experiments.

2. Numerical Simulation Model

2.1 Creating and Simplified Model

In this paper, the small charge of 1.0～5mm detonation propagation characteristic was simulated. The 5mm charge of 45# steel as a example was detailed description. The Fig 1 is experiment instrument of detonation pressure.

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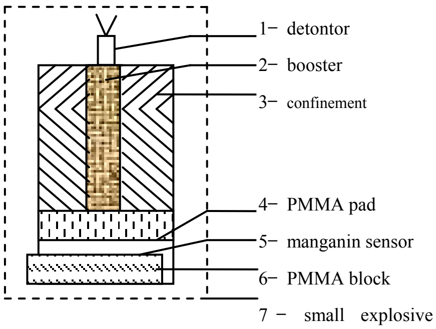


Fig.1 Experiment instrument of detonation pressure

The PMMA pad and block, manganin sensor, small explosive pot all can be abbreviated in testing detonation pressure. The Fig 1 was simplified to Fig 2. Fig 2 is calculated model.

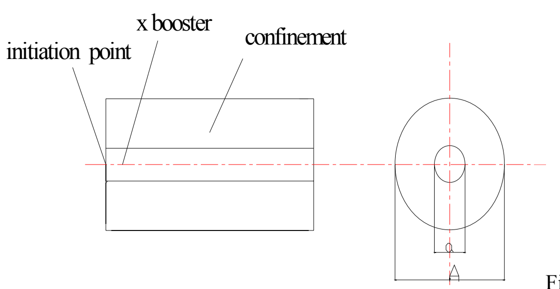


Fig.2

Calculated model

The A=20mm is not changed, but a=5mm、3mm、1mm can changed. Charge diameter is changed with a. The relation of charge diameter and detonation pressure can be defined by numerical simulation.

2.2 Mesh Explanation

High explosive burn model and JWL state equation were selected on detonation products of x booster. Selecting parameter is in Table 1.

Johnson-Cook model and Gruneisen equation were selected on 45# steel confinement. Its selecting parameter is in Table 2. PMMA confinement selecting parameter is in Table 3.

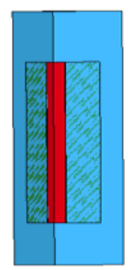
No shear force flow model and linear polynomial equation were selected on air. Selecting parameter is in Table 4.

The mm-kg-ms system of unit was adopted to model.

The altitude of confinement is 38mm and the external diameter is 20mm. The altitude of booster charge is 38mm and the diameter is 5mm. The altitude of air is 60mm and the diameter is 30mm in physical model. The fixed-length hexahedral mapping mesh was adopted in physical model. Euler grid was adopted in modeling of explosive and air, the grid is 0.05mm. Algorithm of Arbitrary Lagrangian Eulerian was used in element.

Point initiation was used in booster charge. The quarter of overall system was accessed on computational model and symmetrical restraint was added in order to economize computing time and improve the calculation precision. The initial stress of all material is zero. The rest boundary all is free interface only confinement charge.

Based on Fig 2 the finite solid model of 45# steel confinement on 5mm charge was established as Fig 3. Fig 4 is finite mesh model. Fig 5 is result on simulation pressure-time for x booster of 45# steel confinement. The rest of pressure-time of different charge is generally similar.



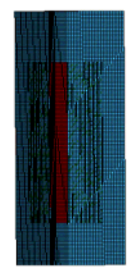


Fig.3 Finite solid model   Fig.4 Finite mesh model

3 Selecting Material and Corresponding Descriptive Equation

3.1Constitutive Relationship of Condensed Explosive and Detonation Product

The form of condensed explosive JWL state equation is:

$$P_e = A_e\left(1-\frac{\omega_e}{R_{1e}}\right)e^{-R_{1e}V} + B_e\left(1-\frac{\omega_e}{R_{2e}V}\right)e^{-R_{2e}V} + \frac{\omega_e E_e}{V} \quad (1)$$

In equation $V=V_e/V_0$ is relative volume, V_e is unreacted specific volume, V_0 is initial specific volume. P_e and E_e is respectively pressure and energy density, A_e, R_{1e}, R_{2e}, ω_e is constant. Be is negative value that can be permitted tension. ω is parameter. These constants are definited by fitting experiment hugoniot data and initial sonic velocity. when $V=1$, $T=298k$, $P_e=0$.

Table 1: Parameters for x booster and detonation product

parameters	*unreacted*	*detonation product*
A/Mbars	9522	7.42
B/Mbars	-0.09544	0.0908
R1	14.1	4.6
R2	1.41	1.3
ω	0.8867	0.39
Cv(Mbars/k)	2.781×10-5	1×10-5
T0/k	298	
E0/Mbars		0.102
CJ detonation parameters		
ρ0(g/cm3)	1.707	
D(mm/μs)	8.208	
Pcj/Mbars	0.33	

3.2 Material Model and State Equation of 45# Steel Confinement

Dynamics response behavior of 45# steel was described by Johnson-Cook model and Gruneisen state equation[11]. The form of Gruneisen state equation is:

$$p=\frac{\rho_0 C^2\left[1+\left(1-\frac{\gamma_0}{2}\right)\mu-\frac{a}{2}\mu^2\right]}{\left[1-(S_1-1)\mu-S_2\frac{\mu^2}{\mu+1}-S_3\frac{\mu^3}{(\mu+1)^2}\right]^2}+(\gamma_0+a\mu)E \qquad (2)$$

When material was expanded,

$$P=\rho_0 C^2\mu+(\gamma_0+a\mu)E \qquad (3)$$

In equation $\mu=\rho_0/\rho-1$, C is static sonic velocity, S1,S2, S3 is hugoniot related parameter, γ_0 is Gruneisen coefficient, a is the first-order volume correction of γ_0. 45# steel selecting parameter is in table 2, σ_s is yield stress.

Table 2: Parameters for 45# steel constraint model

constitutive	***ρ (g/cm3)***	***G/Gpa***	***Pr***	***Tm***	***A***
	7.83	77.0	0	1793	0.792
	B	***N***	***C***	***M***	***σ_s /Gpa***
	0.51	0.26	0.014	1.03	0.09
state	***C(km/s)***	***S1***	***S2***	***S3***	γ_0
	4.569	1.49	0	0	2.17
	a	***E0***	***V0***		
	0.46	0	1.0		

3.3 Material Model and State Equation of PMMA Confinement

Table 3: Parameters for PMMA constraint model

constitutive	***ρ (g/cm3)***	***G/Gpa***	***σ_s /Gpa***	
	1.18	15.0	0.005	
state	***C(km/s)***	***S1***	***S2***	***S3***
	2.561	1.595	0	0
	γ_0	***a***	***E0/Gpa***	***V0***
	1.0	0	0.4220E-02	1.0

3.4 Fluid Model and State Equation of Air

For ALE method, air grid of overlaying all detonation scope was established, and pressure flow was applied to boundary of nodal point in order to avoiding reflection. No shear force flow model and linear polynomial equation were selected on air. Selecting parameter is in Table 4.

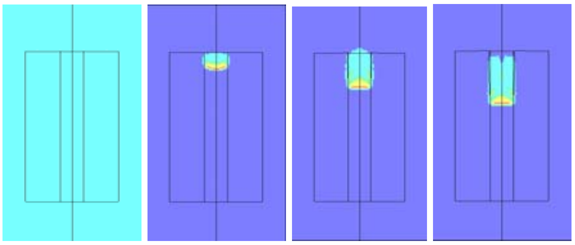
Table 4: Parameters for air fluid model

constitutive	***ρ (g/cm3)***	***Pr***	***Mu***		
	0.001293	0	0		
state	***C0***	***C1***	***C2***	***C3***	
	0	0	0	0	
	C4	***C5***	***C6***	***E0/Gpa***	***V0***
	0.4	0.4	0	0.00025	1.0

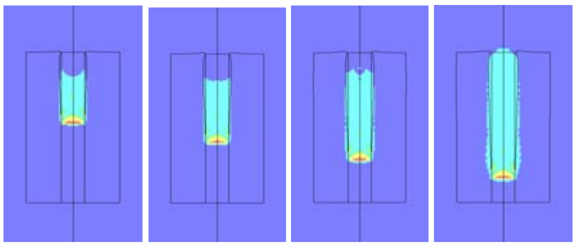
4 Numerical Simulation Results

4.1 Numerical Simulation Results of 45# Steel Constraint

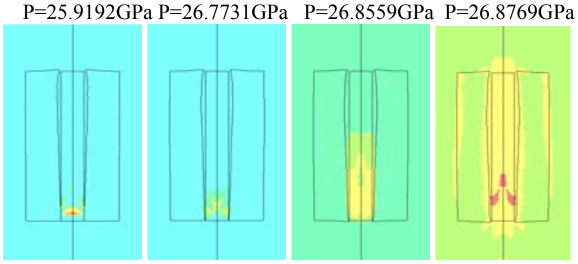
Numerical simulation on charge diameter effecting on detonation pressure solid model is agree with mesh model. Fig 5 is results of simulation pressure-time for x booster charge 5mm of 45# steel constraint.



T= 0μs P＝0GPa | T=0.49496μs P=22.0157GPa | T=0.99784μs P=24.657GPa | T=1.4982μs P=25.7174GPa



T=1.998μs P=25.9192GPa | T=2.4982μs P=26.7731GPa | T=2.9968μs P=26.8559GPa | T=3.4997μs P=26.8769GPa

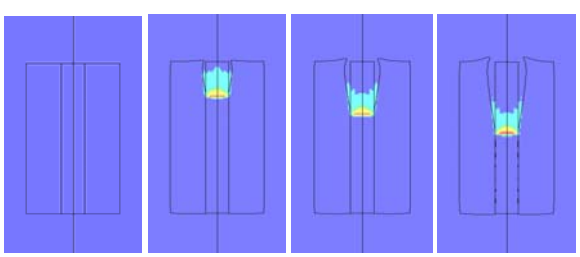


T=3.9992μs P=27.3491GPa | T=4.4984μs P=15.3251GPa | T=4.9977μs P=5.5993GPa | T=5.4978μs P=2.73583GPa

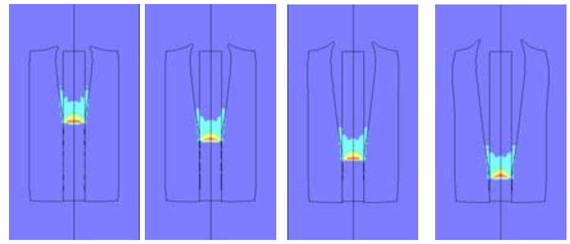
Fig.5 Simulation pressure-time for x booster charge 5mm of 45# steel constraint

Detonation pressure gradually increase with enlarging time, and when T equal to 3.9992μs, P is the biggest value equal to 27.3491GPa, then P gradually reduce until extinguish what can be seen from Fig 5.

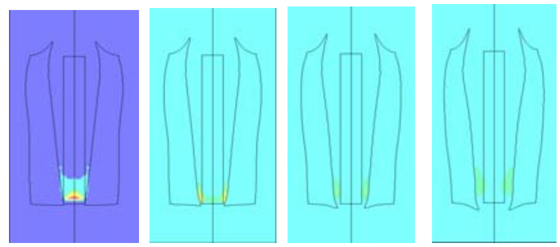
Numerical simulation on charge diameter effecting on detonation pressure of 5mm charge is declared as a example under same PMMA constraint. Fig.6 is results of simulation pressure-time for x booster charge 5mm of PMMA constraint.



T=0μs P=0GPa | T=0.49496μs P=22.5403GPa | T=0.9993μs P=24.6684GPa | T=1.4971μs P=26.1039Gpa



T=1.9974μs P=25.5072GPa | T=2.4962μs P=25.6825GPa | T=2.9999μs P=26.3636GPa | T=3.4963μs P=25.1781GPa



T=3.9963μs P=25.3251Gpa | T=4.4982μs P=5.39554GP | T=4.9999μs P=3.57735GPa | T=5.4976μs P=2.6286GPa

Fig.6 Simulation pressure-time for x booster charge 5mm of PMMA constraint

Detonation pressure gradually increase with enlarging time, and when T equal to 2.9999μs, P is the biggest value equal to 26.3636GPa, then P gradually reduce until extinguish what can be seen from Fig 6.

4.2 Matching Results of Simulation and Experiment

The corresponding detonation pressure is simulated by changing charge diameter. The results are displayed in Table 5.

Table 5: Simulation and testing of detonation pressure for small charge x booster

diameter /mm	*45# steel/GPa*		*PMMA/GPa*	
	simulation	*experiment*	*simulation*	*experiment*
5	27.3491	26.47	26.3636	25.65
3	25.1153	24.32	23.2322	22.32
1.5	17.5039	14.36	15.4520	12.45
1	12.4638	—	11.0946	—

Note: The experiment value that is inverse value after attenuating PMMA pad is detonation pressure value of PMMA interface.

Fig 7 and Fig 8 are obtained by using Origin8.0 fitting curve from Table 5.

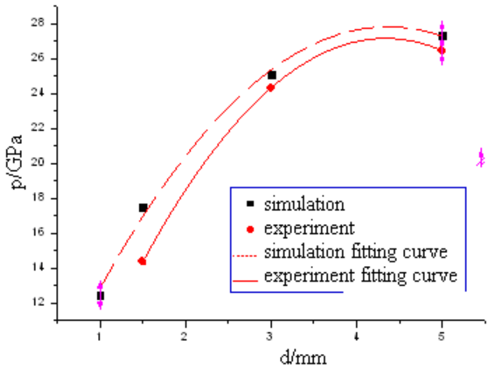


Fig.7 The 45# steel constraint fitting curve of experiments and numerical simulation results

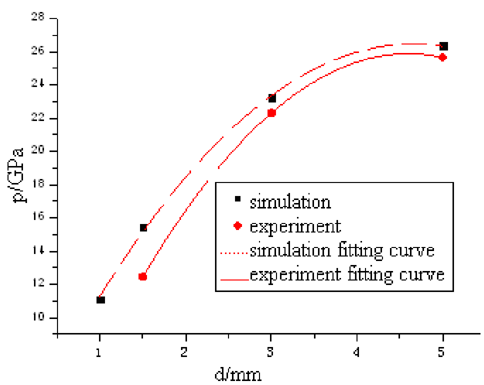


Fig.8 The PMMA constraint fitting curve of experiments and numerical simulation results

Detonation pressure is enlarged with charge diameter enlarge under the same constraint can be seen from Fig 7 and Fig 8. Under the same charge, detonation pressure of 45# steel is bigger than PMMA. The charge of 45# steel is superior in the axial detonation propagation.

The resistance of 45# steel is bigger than PMMA, and deformation of PMMA is clearly bigger than 45# steel, this is agreed with experiment and theory. But the result of simulation is clearly bigger than experiment. The small variance is existed from them. The results of experiment is deviated of simulation because of losing radial energy. Simulation is entirely depending on mathematical model. Some simplified treating was inevitable proceeded in establishing model. The results of simulation is appeared deviation because of ignoring some influencing factor. Propagation of the detonation wave for small-charge is no steady and polytrophic complex process. Input parameter in mathematical model is usually relative constant or variable in limited range. True case was not really reflected by model parameter what causing distortion of simulation result.

5 Conclusion

(1) Detonation pressure is enlarged with charge diameter enlarge under the same constraint.
(2) Under the same charge, detonation pressure of 45# steel is bigger than PMMA. The charge of 45# steel is superior in the axial detonation propagation.
(3)Nonlinear dynamic 3D-finite programming of LS-DYNA, ALE algorithm and constrained Lagrange in solid method were used to simulate the non-ideal detonation process for x booster in small charge. The result of simulation is agree with experiment. The constitutive model and parameters are suitable in the paper.

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