Research paper

Numerical simulation of explosion process of a precise detonator

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Abstract

For analyzing detonation process of the concave-bottomed and flat-bottomed precise detonators, numerical simulations of detonators were carried out by using the nonlinear finite element code LS-DYNA. The simulation results of two type detonators are compared with each other. The expansion of detonation product is reproduced. It is consistent with results taken by the high-speed camera. The results can provide a base for further study, such as rock blasting etc.

Keywords: Detonator, Explosion, Finite element, Numerical simulation

1. Introduction

A detonator is a device used to trigger explosive in all kind of blasting engineering. Detonators can be found in either electrical or non-electrical form. Detonators vary in size and strength. The mainly detonators used for civil applications are #6 and #8 blasting caps [1]. There are so many different types of blasting caps with different primaries and sizes that it is nearly impossible to put a number to a detonator any more.

Simulation of the detonation of a detonator is complicated, involving a detonation causing a shock wave propagation and then interaction with copper shell. A suitable computational tool is very important. In this paper, the numerical simulations of detonation process inside the concave-bottomed and flat-bottomed detonators were carried out. LS-DYNA was used for those simulations. The simulation results of two type detonators were analyzed.

2. A precise detonator and FE model

A precise detonator is a wire explosion detonator produced by Nippon Kayaku Co. ltd [2]. It is composed of primary charge, secondary charge, copper tube and leg wire. PETN is used in primary charge and secondary charge, their weights are 0.4 g and 0.3 g respectively, and their lengths are 23 mm and 9.5 mm respectively. The experimental setup is shown in Fig. 1. Explosive charges and copper tube are concerned mainly in the finite element model. By making use of symmetry, only 1/2 of the structure is modeled, two-dimensional elements are generated

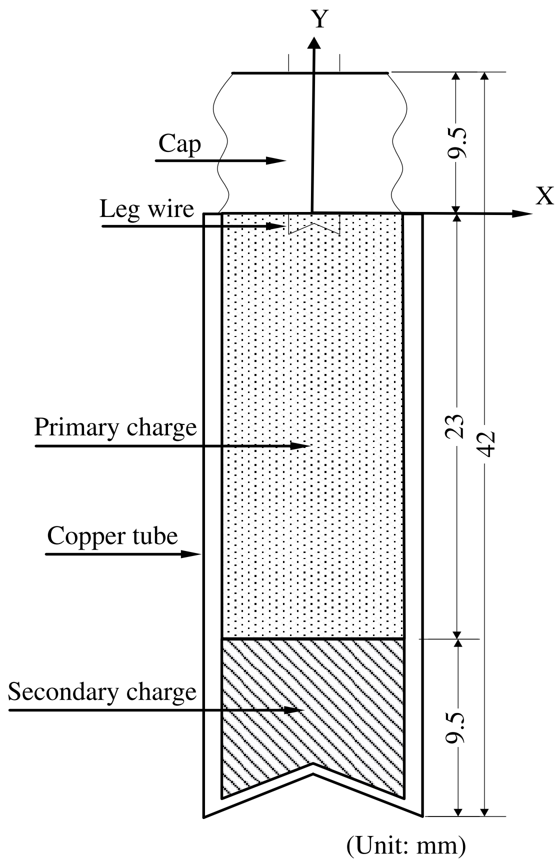


Fig. 1 Configuration of precise detonator.

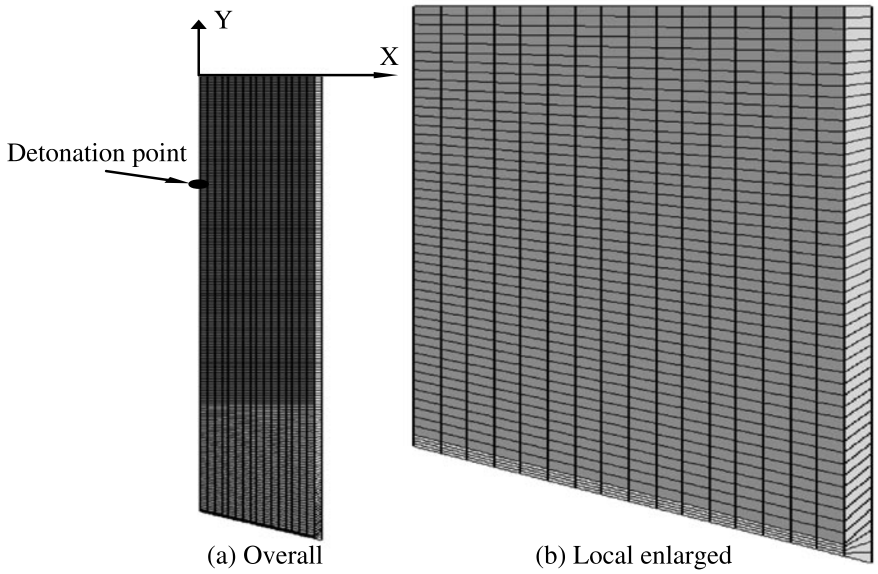


Fig. 2 Finite element model.

Table 1 Detonation and JWL parameter of PETN.

	Density ($g \cdot cm^{-3}$)	Detonation velocity ($m \cdot s^{-1}$)	*CJ* pressure (Gpa)	*A* (Gpa)	*B* (Gpa)	R_1	R_2	ω	*E* (Gpa)
Primary charge	0.58	4154	3.079	62.97	1.8	5.65	1.35	0.19	4.0
Secondary charge	1.17	6394	12.7	421.5	9.4	5.58	1.4	0.28	7.4

PETN: by RIO-DB by Dr. Katsumi Tanaka

Table 2 Grüneisen parameter of copper.

	Density ($g \cdot cm^{-3}$)	Shear modulus (Gpa)	Yield stress (Gpa)	Failure strain	*C* ($m \cdot s^{-1}$)	S_1	S_2	γ_0	α
Copper[4)]	8.93	47.7	0.64	0.7-1.1	3940	1.5	0.6	1.99	0.47

by using axisymmetric solid (y-axis of symmetry) [3)]. The meshes for all materials are modeled as Lagrangian meshes. 3052 elements and 3420 nodes are included. Nodes belonging to the x-coordinate (y=0) are constrained translation in local x-direction and y-direction. The detonation point is located at 8 mm below the coordinates. Figure 2 shows the finite element model.

The explosive detonation has been modeled using a JWL equation of state, its expression is:

$$P = A\left(1-\frac{\omega}{R_1V}\right)\exp\left(-R_1V\right)+B\left(1-\frac{\omega}{R_2V}\right)\exp\left(-R_2V\right)+\frac{\omega E}{V} \quad (1)$$

Where *A, B,* R_1, R_2, ω are JWL parameters; *E* is the specific internal energy. Values of PETN were calculated by using RIO-DB database which is established by Dr. Katsumi Tanaka, AIST. Based on this database, the different material properties of the primary and secondary charge were obtained when the different density each other was inputted.

An elastic plastic hydro type copper tube is modeled. The dynamic value of yield stress is very difficult, so we assumed that it is 0.64 Gpa. The equation of state for copper in this study is used Grüneisen equation. This equation is shown below:

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

For expanded materials as:

$$P=\rho_0 C^2\mu+\left(\gamma_0+\alpha\mu\right)E \quad (3)$$

Where *C,* S_1, S_2, S_3 are constant of material, γ_0 is the Gruneisen coefficient; α is the first order volume correction to γ_0; and $\mu = \rho / \rho_0 - 1$. Table 1 and Table 2 list each coefficient for explosive and copper.

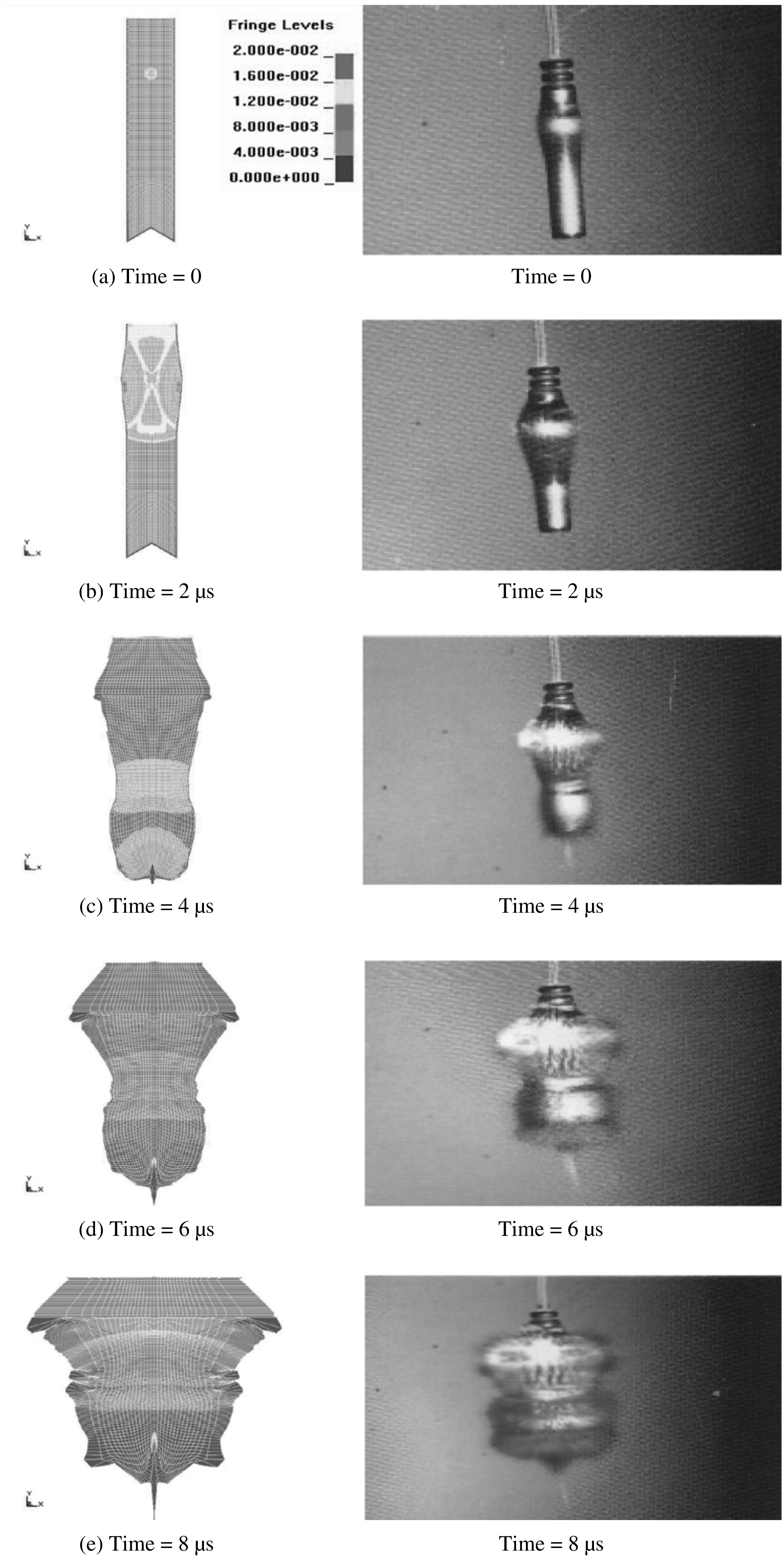


Fig. 3 The results of simulation and experiment of concave-bottomed detonator (contour of pressure).

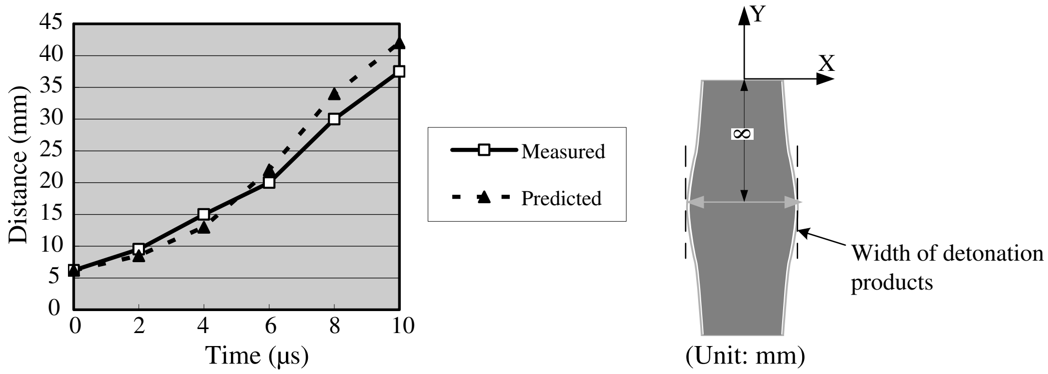
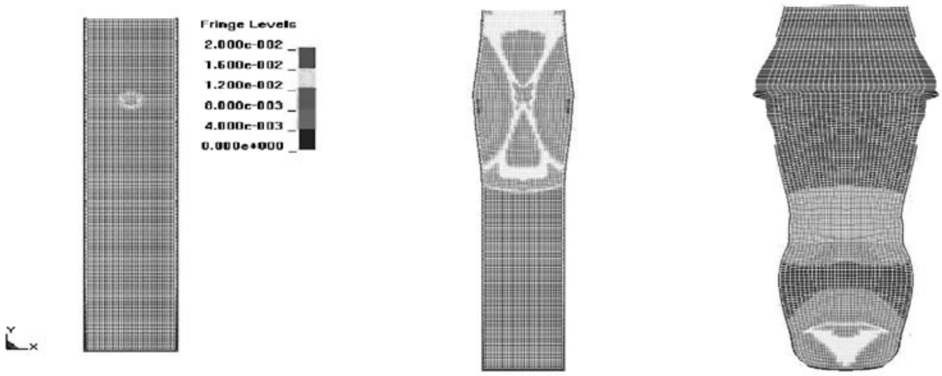


Fig. 4 Width of detonation product.



(a) Time = 0 (b) Time = 2 μs (c) Time = 4 μs

(d) Time = 6 μs (e) Time = 8 μs

Fig. 5 The simulation results of flat-bottomed detonator (contour of pressure).

3. Results and discussions

3.1 The simulation results of concave –bottomed detonator

Figure 3 shows the results of the simulations and experiments. These experimental photos are provided by an author in reference [2]. Figure 3 (a) and (b) shows that detonation wave spreads in the primary charge from ignition to 2 μs. After passing by interface of explosive and copper shell, the detonation wave generates reflection, and the reflected wave overlaps upon the central axis forming the high-pressure region. The copper shell expands in radial direction by shock stress acting on the shell. From Fig. 3 (c), (d) and (e), at round time= 4 μs, the copper shell nearby the primary charge firstly takes place plastic failure. At the same time, the secondary charge has been detonated. When the detonation wave reaches the conical copper liner, the intense pressure generated by focusing of the explosive's energy forces the tip of the cone to collapse and form a high- velocity jet along the axis. From 6 μs to 8 μs, the expansion of detonation products becomes bigger and bigger with increasing jet synchronously along with the propagation of detonation wave.

Figure 4 shows the comparison of the width of detonation products. The predicted values agree well with the measured results. The discrepancies between the predicted and the measured values are from 2 % to 15 % respectively.

3.2 The simulation results of flat- bottomed detonator

Figure 5 shows the simulation results of flat-bottomed detonator. Compared with Fig. 3, the propagation of the detonation wave and the plastic failure of copper shell of the flat-bottomed detonator are completely same with that of concave- bottomed detonator before the detonation wave reaches the detonator bottom. However, the differ-

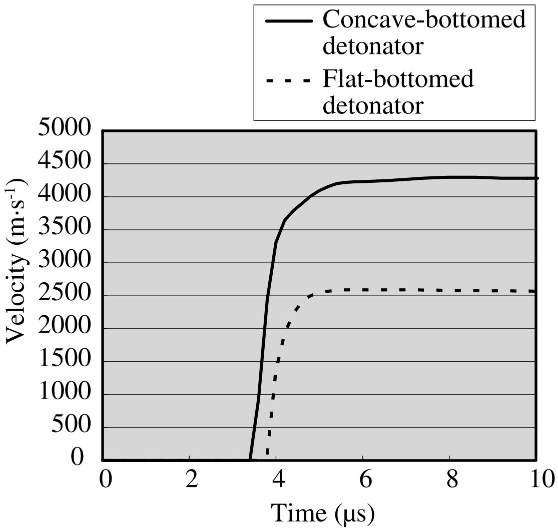


Fig. 6 The tip-velocity vs time.

ence appears after detonation wave reaches the detonation bottom. In the concave-bottomed detonator, explosive energy is released directly away from (normal to) the surface of an explosive. So the conical copper liner can concentrate explosive energy upon the central axis. The resulting energy drives the copper liner collision to project a jet of metal forward along axis. But in the flat-bottomed detonator, as shown in Fig. 5 (c), the detonation wave reaches the copper liner simultaneously without focusing blast, so acted by pressure, the plate liner moves outward along axis. On the other hand, the moving plate deforms and forms convexity due to the pressure near the central axis is bigger than one of the both sides.

Figure 6 shows the comparison of the jet's tip-velocity of two type detonators. The tip-velocity is 4280.7 $m \cdot s^{-1}$ for the concave-bottomed detonator, compared with 2590.2 $m \cdot s^{-1}$ of the flat-bottomed detonator. It is clearly shown that the concave-bottomed detonator noticeably increases the tip-velocity of jet.

4. Conclusions

The numerical simulation models of concave-bottomed and flat-bottomed detonators were established, the detonation process of detonator was simulated, and the computational results were reasonably good compared with the experimental results. These works are valuable for the further development of new detonator. The results indicate numerical simulation provides a helpful tool to study the detonation of detonator.

Acknowledgements

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