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NUMERICAL SIMULATION OF FORMATION OF EFP WITH CHARGE OF ALUMINIZED HIGH EXPLOSIVE

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In this paper, three dimensional finite element code LS-DYNA is used to simulate the dynamic deformation process of EFP with truncated spherical liner that initial liner material experiences from explosive shock acceleration through to the final formation of the aerostable geometry. The velocity and shape of EFP is obtained. In order to study the effect of the charge, two high explosives, Comp-B and aluminized high explosive (PBXN-111), have been chosen. The calculation results show that aluminized high explosive improves the velocity of EFP.

INTRODUCTION

Explosively Formed Projectile (EFP) is formed by high explosives, which has high speed with good pneumatic shape. Compared with the jet, EFP has larger mass and diameter, so that it can penetrate large volume cavity in high-intensity target. In addition, the stand-off has little effect to EFP.

In order to improve the density of energy content, a large number of researches have been conducted on composite explosive, and one of the important ways is to add metal particles to the explosive. In 1900s, the aluminium powder is added to the explosive to enhance the power, as the oxidizing reaction of aluminium powder releases energy at the time of explosion. M. Finger et al systematically studied the work capability of the aluminized high explosive by experiments, as the result, the aluminium powder and oxygenant could increase the capability of explosive to drive metal[1].

In this paper, three dimensional finite element code LS-DYNA is used to numerically simulate the dynamic deformation process of EFP that initial liner material experiences from explosive shock acceleration to the final formation of the aero stable geometry with charge of Comp-B and aluminized high explosive PBXN-111[2]. The velocity and shape of EFP is obtained. The calculation results of shape and velocity of EFP are in good agreement with experimental ones. Additionally, as a textual research of the reliability of numerical method, test of aluminized high explosive driving metal plate is calculated, which corresponds with results in the reference[1].

NUMERATION MODEL AND MATERIAL CONSTITUTIVE EQUATIONS

Figure 1 is the configuration of the EFP setup, which contains the explosive, the shell and the liner. The material of shell and liner is steel, and the explosive is ignited at the center in rear end. Lagrange method is used, and the mesh division of the EFP model is showed on figure 2.

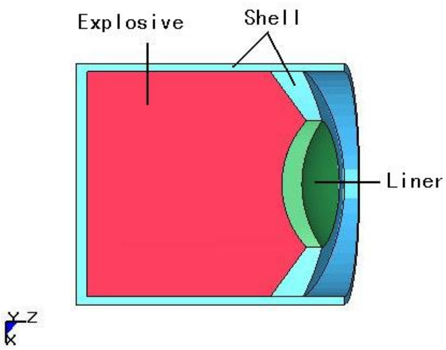

Figure 1. Configuration of the EFP setup

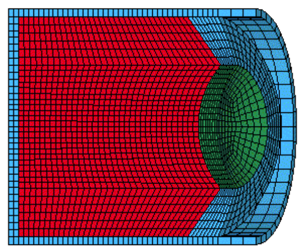

Figure 2. Mesh of the EFP model

The high explosive used in this setup is COMP-B and PBXN-111. In calculation equation of state is JWL for Comp-B.

$$p = A\left(1-\frac{\omega\eta}{R_1}\right)e^{-\frac{R_1}{\eta}} + B\left(1-\frac{\omega\eta}{R_2}\right)e^{-\frac{R_2}{\eta}} + \omega\rho e \tag{1}$$

Here, A, B, R_1, R_2 and ω are fitting coefficients by experiments, ρ is density, e is internal energy, $\eta = \rho/\rho_0$, ρ_0 is initial density. The parameters are presented in [3].

For aluminized high explosive PBXN-111, ignition-growth model is used to calculate the formation process of EFP. Reaction rate of high explosive of ignition-growth model is the following:

$$\frac{\partial F}{\partial t} = I(1-F)^b \left(\frac{\rho}{\rho_0} - 1 - a\right)^x + G_1(1-F)^c F^d P^y + G_2(1-F)^e F^g P^z \tag{2}$$

where F is the fraction of reacted explosive, ρ is the current density, ρ_0 is the initial density, p is pressure, and I, G_1, G_2, a, b, c, d, e, g, x, y, and z are constants. Upper threshold limits F_{mxig}, F_{mxGr} and F_{mnGr} are set to limit the contributions of the three terms to respectively; a maximum reacted fraction F_{mxig} for the first term, a maximum fraction F_{mxGr} for the second term and a minimum fraction F_{mnGr} for the last term. Accordingly, the ignition rate is set equal to zero when $F \geq F_{mxig,}$ the growth rate is set to zero when $F \geq F_{\text{mxGr}}$, and the completion rate is set to zero when $F \leq F_{mnGr}$. The equation of state of PBXN-111 is also JWL form. Parameters of PBXN-111 are from reference [2].

The material of liner and shell is steel. Constitutive relationship of steel is Steinberg model and equation of state is Gruneisen model. In Steinberg constitutive model[4], the effect of pressure, temperature and plastic strain rate on yield strength and shear module was considered. Before the material melts, the shear module is defined as:

$$G = G_0\left[1 + bpv^{1/3} - h\left(\frac{e-e_c}{3R'} - 300\right)\right]\exp\left(-\frac{fe}{e_m - e}\right) \tag{3}$$

where p is pressure, ν is the relative volume, G_0, b, h and f are parameters of material by experiments, e_c is the cold compression energy, e_m is the melting energy, e is internal energy, $R' = R\rho / A$, R is gas constant, ρ is density, A is the atomic weight. The yield strength σ_y is given by:

$$\sigma_y = \sigma_0'\left[1 + b'pv^{1/3} - h\left(\frac{e-e_c}{3R'} - 300\right)\right]\exp\left(-\frac{fe}{e_m - e}\right) \tag{4}$$

Here, σ'_0 and b' are material constants. The parameters in the calculation can be seen from reference [4].

The equation of state Gruneisen is,

$$p=\frac{\rho_0 c_0^2 \mu(1+\mu)}{\left[1-(s-1)\mu\right]^2}+\gamma\left[\rho e-\frac{1}{2}\frac{\rho_0 c_0^2 \mu(1+\mu)}{\left[1-(s-1)\mu\right]^2}\frac{\mu}{1+\mu}\right] \tag{5}$$

Where $\mu = \rho/\rho_0 - 1$, c_0 is the intercept and s is the coefficient of the slope of the Rankine-Hugoniot (u_s -u_p) curve, the value of c_0 is 4.693 km/s, s is 1.339, and Gruneisen coefficient γ is 1.997.

RESULTS OF THE NUMERICAL ANALYSIS

First, test of aluminized high explosive driving metal plate is calculated. Figure 3 is the configuration. The model and the parameters are from reference [2]. The aluminized explosive charge used in the test has the same composition with PBXN-111(43% AP, 25% Al, 20% RDX, 12% HTPB). The flyer is steel plate.

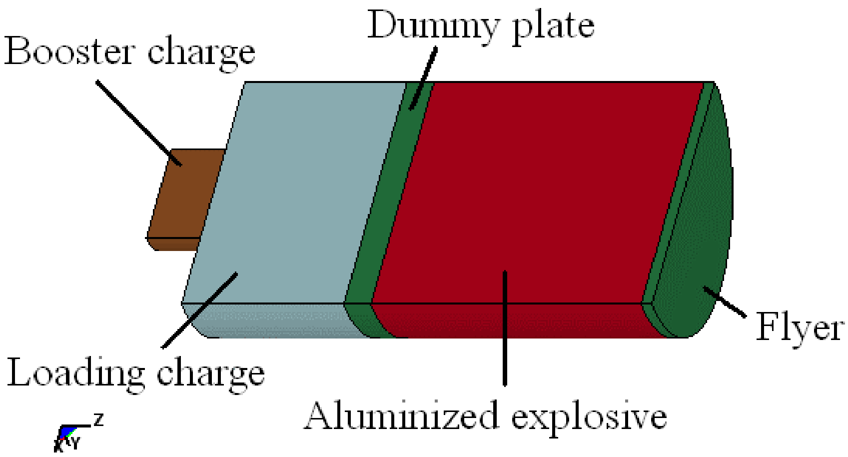

Figure 3. Configuration of aluminized explosive driving metal plate

Figure 4 indicates the velocity of flyer. The calculation results correspond with test results well expect that calcultion results are little high than test ones at late time.

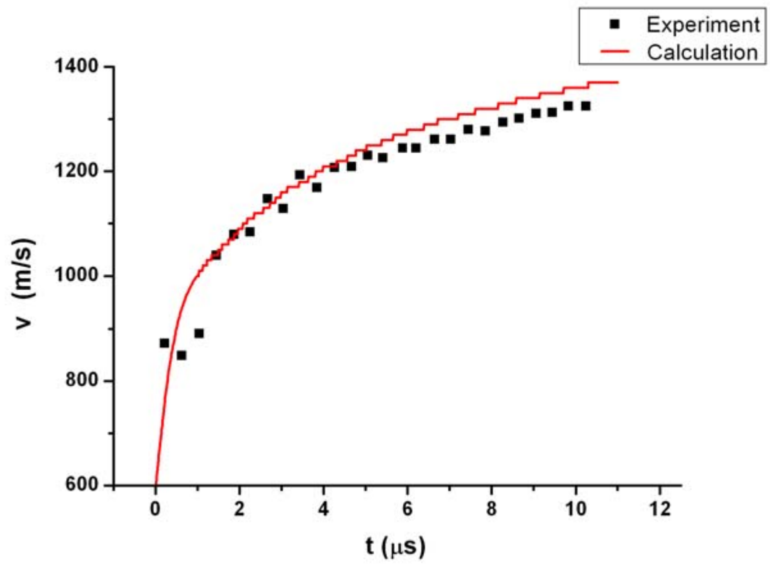

Figure 4. Comparison of the velocity of flyer between calculation and experiment
Black scatter point is experiment; red line is calculation.

Then, numerical simulation of the dynamic deformation process of EFP is presented. Figure 5 is the formation process of EFP with charge of Comp-B. As t = 60μs, the liner is compressed to be like a straw hat. As t = 120μs, EFP has almost formed. As t = 150μs, projectile tends to be steady at velocity 1.582 km/s, and the projectile keeps unchanged.

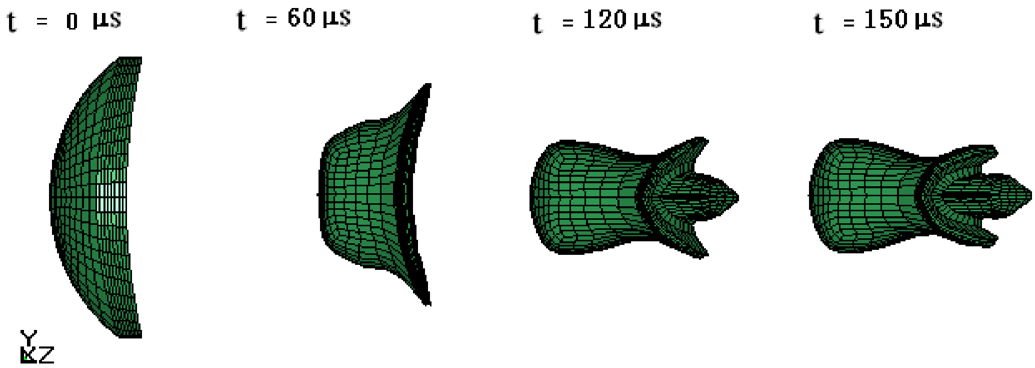

Figure 5. Formation process of EFP with the Comp-B

Figure 6 is the formation process of EFP with charge of aluminized high explosive

PBXN-111. The velocity of projectile is 1.72km/s as it tends steady. Its rear end is flatter than EFP with Comp-B.

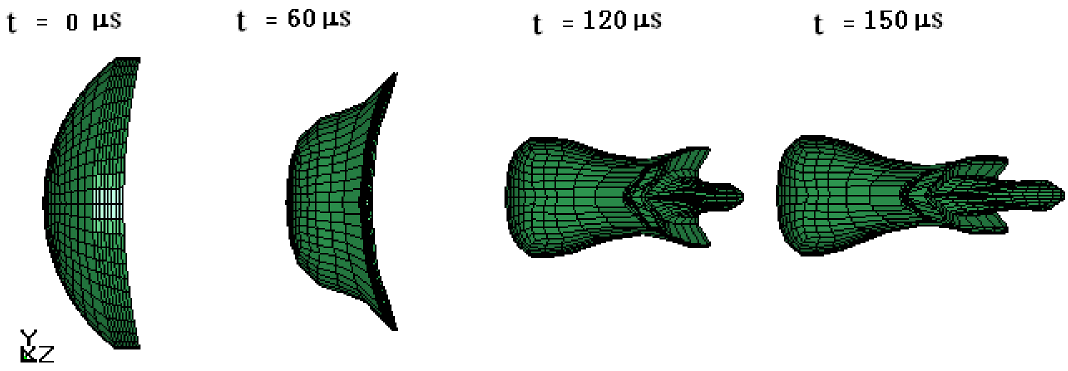

Figure 6. Formation process of EFP with the PBXN-111 explosive

Comparison of the shape and velocity EFP with Comp-B and PBXN-111 is showed in table 1. And the velocity of EFP with charge of aluminized high explosive is about 8.9% higher than that with Comp-B; the kinetic energy is increased 18.5% because of the higher density and explosive energy of aluminized high explosive.

Table 1. Comparison of size and velocity of EFP with Comp-B and PBXN-111

	Cross-section size of EFP (cm) Calculation	velocity of EFP (km/s) Calculation
Comp-B	5.2 × 7.4	1.58
PBXN-111	5.2 × 7.3	1.72

CONCLUSION

Dynamic deformation process of EFP is numerically simulated. Final velocity and shape of EFP is obtained. Numerical simulation shows that the velocity of EFP with charge of aluminized high explosive PBXN-111 is higher than that with Comp-B.

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