

# Numerical Simulation of Shock Initiation on Solid Rocket Propellant

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**Abstract:** As the safety of propellant has been paid more and more attention, the experiment of explosive-driven flyer impacting initiation propellant was simulated by nonlinear finite element software Autodyn17.0. The results show that the critical initiation pressure of the high energy propellant is about 2.95 GPa, the detonation wave growth distance is about 20-25 mm, and the highest pressure is 48.40 GPa.

## 1. Introduction

In modern war, with the increase in the use frequency of rocket weapons, the safety of solid rocket engines has received greater attention. In process of production, transportation, and use, it may be affected by external factors such as bullets, fragments, and shock waves because of unpredictable reasons. Due to the need for a more powerful solid rocket in the war, the solid rocket propellant includes a kind of explosive component such as HMX, which makes the solid rocket propellant more unstable than that of the double-base(DB) or tri-component propellant.

Bai Chunhua and Ding Jing studied the shock initiation and detonation of two composite propellants, whose binders are thiokol and HTPB, respectively, by using the Lagrangian gauge and Lagrangian analysis technique [1]. Huang Fenglei designed a set of testing systems for shock initiation of damaged propellant and studied the process of deflagration to detonation transition (DDT) under strong and weak boundary [2]. Wu Junying et al. carried out the researches about the characters of high energy solid propellants initiated by shock waves and designed a Langrange analytical experiment equipment [3]. Cui Hao determined the parameters of JWL equation of state of detonation product for propellant on the basis of the cylinder test and numerically simulated the falling process of solid motor [4].

In this paper, the process of explosive-driven flyer plate impacting a solid rocket propellant is simulated. The device refers to the device designed by Chen Lang et al. to drive the flyer plate to impact the heated explosive. Driving the flyer by the gas gun needs a target chamber with strong anti-explosion ability. The experimental system is complex and costly, and the experimental explosive quantity is also limited [5]. Shock initiation experiment by means of explosive-driven flyer plate has low cost and is convenient to operate. The Lee-Traver ignition and growth model is used to simulate the impact ignition characteristics of the propellant under the shock wave. The different impact velocity and impact pressure on the influence of overpressure produced by propellant detonation are analyzed. This paper may provide a certain reference for such experiments.

## 2. Numerical Simulation

### 2.1. Numerical Simulation Model

The experiment equipments include detonation, explosive lens for getting a planar shock wave, TNT as donor explosive, flyer plate, Al clapboard, propellant, pressure gauge and base, as shown in Figure 1. The flyer plate, Al clapboard and base are connected by hexagon bolts.

The nonlinear finite element fluid dynamics method (Autodyn17. 0) was used to simulate the process of flyer plate impacting the solid propellant [6]. The connector is ignored in the model, and since the purpose of the explosive lens is to generate a plane shock wave, the detonator and the

explosion lens are replaced by a line detonation. The whole model is an axisymmetric model, so it is built using a 2D axisymmetric model. The pressure gauge points are put on propellant as Figure 2. The material of Al plate is Al 7039, using the Shock equation of state and the Johnson Cook strength model to describe the constitutive relationship. The material of flyer plate is steel 1006, using the Shock equation of state and the Johnson Cook strength model to describe the constitutive relationship.

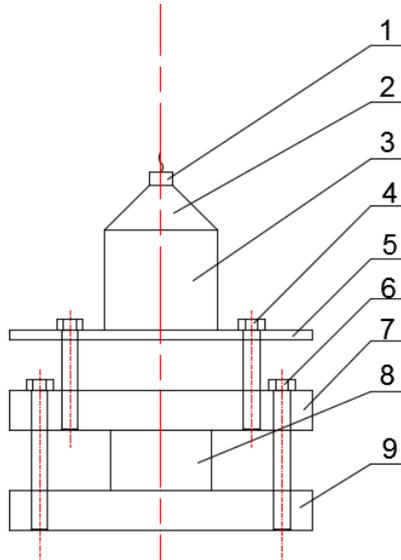


Figure 1 Schematic of shock initiation experiment by explosive-driven flyer plate. 1—detonation; 2—detonation lens; 3—donor explosive , TNT; 4, 6—hexagon bolts; 5—flyer plate; 7—Al clapboard; 8—propellant; 9—base.

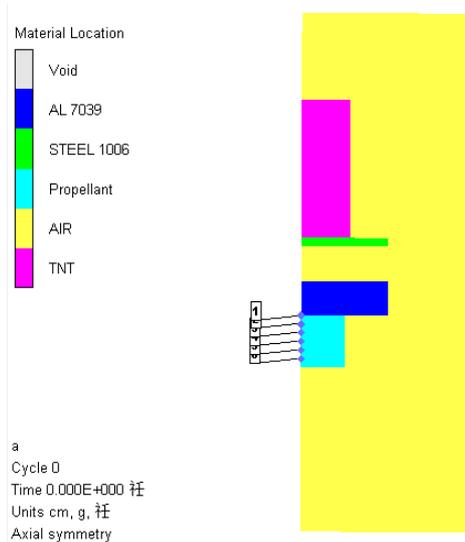


Figure 2 Finite element 2D model of shock initiation experiment by explosive-driven flyer plate.

The propellant is described as Lee-Traver equation, which includes three equations: two Jones-Wilkins-Lee (JWL) equations of state and a reaction rate equation [7]. Two JWL equations of state, one of them is for the unreacted explosive and another is for reaction products, in the form:

$$p = Ae^{-R_1v} + Be^{-R_2v} + \omega C_v T/V \quad (1)$$

where  $p$  is pressure in GPa of propellant,  $V$  is relative volume,  $T$  is temperature of propellant in K,  $\omega$  is the Gruneisen coefficient,  $C_v$  is the average heat capacity, and  $A$ ,  $B$ ,  $R_1$  and  $R_2$  are constants. The reaction rate equation is:

$$\lambda = \frac{dF}{dt} = I(1 - F)^b \left(\frac{\rho}{\rho_0} - 1 - a\right)^x + G_1(1 - F)^c F^d p^y + G_2(1 - F)^e F^g p^z \quad (2)$$

where  $\lambda$  is the ratio of the fraction reacted,  $F$  is the fraction reacted of propellant,  $t$  is time in  $\mu\text{s}$ ,  $\rho$  is the current density of propellant,  $\rho_0$  is the initial density of propellant,  $p$  is pressure in Mbars, and  $I$ ,  $G_1$ ,  $G_2$ ,  $a$ ,  $b$ ,  $c$ ,  $d$ ,  $e$ ,  $g$ ,  $x$ ,  $y$ , and  $z$  are constants. In this paper, the parameters of the Ignition and Growth Modeling adopted in this paper refer to the Cui Hao's paper as Table 1 and 2 [4].

Table 1 JWL equation of state parameters for propellant.

$\rho_0/$ ( $\text{g}\cdot\text{cm}^{-3}$ )	$D/$ ( $\text{m}\cdot\text{s}^{-1}$ )	$R_1$	$R_2$	$\omega$	$A/$ GPa	$B/$ GPa
1.836	9130.4	5	1.82	0.2	909.59	62.05

Table 2 Parameters of the reaction rate equation for propellant.

$I$	$b$	$a$	$x$	$G_1$	$c$	$d$	$y$	$G_2$	$e$	$g$	$z$
44	0.222	0.01	4	111	0.222	0.667	1.66	200	0.333	0.667	2

## 2.2. Numerical Simulation Results

The pressure and reactivity of the Gauge points on propellant are shown in Figure 3. Due to the existence of boundary sparse waves, the central part of the steel flyer is subjected to the shock wave whose pressure is 34.26 GPa, and the Al clapboard is impacted by the steel flyer at a speed of 1550 m/s. The Gauge points and their velocities on the steel flyer are shown in Figure 4. After buffering with the Al clapboard, the surface of the propellant received an impact of a pressure about 5.50 GPa at 28.05  $\mu\text{s}$ . The shock pressure of Gauge point 1 is 5.54 GPa. The shock wave creates hot spots on the propellant, resulting local reaction of the propellant. At the position of Gauge point 2, the shock pressure grows to 18.95 GPa, and the reactivity has reached 1, but the threshold pressure of detonation has not yet reached. When the shock wave propagates to Gauge point 3, the detonation wave is completely formed and the degree of reaction quickly reaches 1. Therefore, it can be seen that the propellant detonation wave growth distance is about 20-25 mm. The highest pressure is 48.40 GPa.

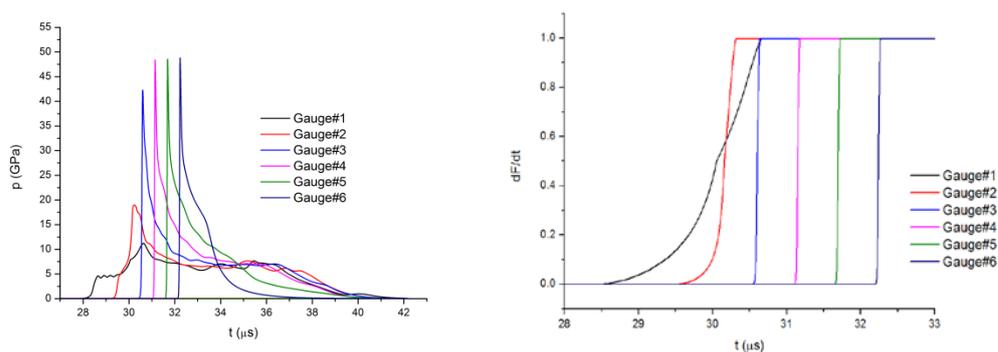


Figure 3 The pressure and reaction rate history of Gauge points in propellant, and the shock pressure is about 5.50 GPa.

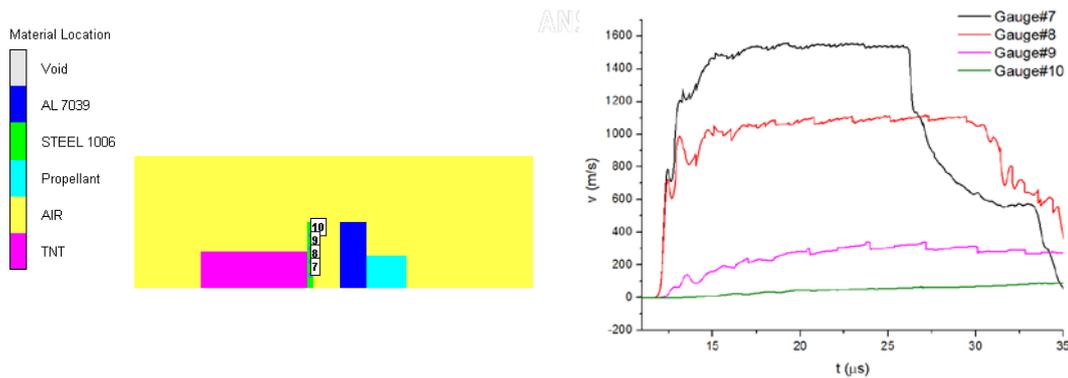


Figure 4 The Gauges in flyer plate and the velocity history of Gauge points.

When the shock pressure is reduced to 2.70 GPa, the pressure history is shown in Figure 5. The propellant cannot completely react (only about 10%). Based on the dichotomy, the critical initiation pressure of the high-energy propellant is about 2.95 GPa after several simulations.

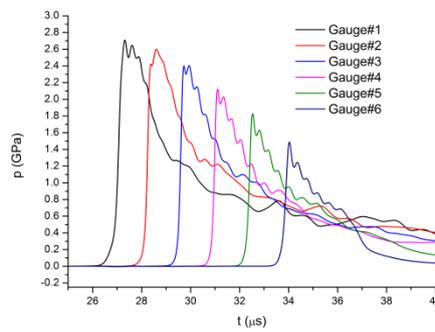


Figure 5 The pressure of Gauge points in propellant and the shock pressure is about 2.70 GPa.

### 3. Conclusion

The detonation wave growth distance of the high-energy propellant can be obtained to be about 20-25 mm by simulating the process in which explosive-driven flyer plate impacting a solid rocket propellant. The critical reaction pressure is approximately 2.95 GPa. The smaller the shock pressure, the smaller the reaction rate.

### References

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