INFLUNCE OF THE SOURCE ENERGY CONDITIONS ON CYLINDRICAL DETOANTION IN TWO-DIMENSIONAL SIMULATION

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Summary Two-dimensional simulations of cylindrical detonation (CD) are performed using compressible Euler equations in Cartesian coordinate system and a two-step chemical kinetic model. The validation of numerical method is first discussed to ensure that it can reproduce the folwfieds of CD. And then the deposited energy in the source region is calculated and compared to experimental data, ensuring that the failure of CD in the following simulations is not because of the shortage of energy. At last, the influence of the source energy conditions on the formation of CD is described and analyzed.

INTRODUCTION

The studies of unconfined detonation have been done by many researchers since the work done by Zel'dovich [1]. They analyze the phenomena both theoretically and experimentally, and most focus on the critical energy and failing mechanism. As the numerical methods developing, researchers began to study the problem numerically from one-dimensional to two-dimensional model [2,3] to better understand the propagation mechanism of cylindrical detonation or spherical detonation. In this paper, we will focus on the source energy conditions-the source pressure (p_s), the source temperature (T_s) and the source radius (R_s)-to give detail description of their influence on the formation of CD in unconfined conditions, using two-dimensional simulation model.

NUMERICAL METHOD

The governing equations are the two-dimensional compressible Euler equations in Cartesian coordinate system with source terms due to chemical reaction. And the two-step chemical kinetic model is used to simplify the actual reaction. Flux terms are solved by five-order MPWENO. Time integration is performed using the third-order TVD Runge-Kutta method. Above methods have been used successfully to simulate the flow field of rotating detonation engines.
The numerical domain consists of the quarter plane $x \geq 0$, $y \geq 0$, with symmetry boundary conditions at four boundaries. The grid size in both the x and y direction is 0.1mm. At the initial state, the domain is filled with premixed stoichiometric H_2/O_2 mixtures with pressure p_0=1atm and temperature T_0=300K. In the source region ($x^2 + y^2 \leq R_s^2$) p_s and T_s are set high to provide the initiation energy.

RESULT AND DISCUSSION

At first, the validation of numerical methods is discussed. Next, the calculation of source energy is talked about. And then the influence of initial source energy conditions (p_s, T_s and R_s) on the formation of CD is described and analyzed.

Validation of numerical methods

Fig 1 shows the maximum pressure history across the whole domain in the first time period of 21.5μs. At the outer radius, the cellular structure can be seen clearly and shows similar feature with that observed by Soloukhin [4] experimentally and by Asahara et al. [3] numerically. The past experimental studies by Vasilev and Trotsyuk [5] also showed the smoked-foil record and reported that new cells must be generated in order to maintain a constant average cell size. And the numerical studies [3] shows that the cell sizes near the line 45^o from x-axis are larger than those near the x-axis or y-axis. However, in the present simulation, the result is just opposite, for the cell sizes near the two axes are slightly larger. Moreover, the cellular pattern becomes regular as CD propagates outwards. Therefore it can be safely concluded that the numerical methods used here are able to simulate the flowfields of CD. Once generated transverse waves are distributed uniformly, CD can propagate stably and keep self-sustaining afterwards. Therefore, uniform distribution of triple points along detonation front is treated as sign of successful CD in the following studies.

Calculation of the critical energy

According to the semi-empirical equation ($E_c = 4\pi\gamma p_0 M_{CJ}^2 I(13\lambda/4)^2$) proposed by Lee [6] and the experimental result reported by Litchfield et al [7], the critical energy for successful spherical detonation is about 10J. To compare with above data, CD is taken as two-dimensional spherical detonation and the small source region as point source. Therefore, the deposited energy can be calculated by $E_s = 4\pi R_s^3 p_s / 3(\gamma - 1)$, based on the internal energy for a perfect gas. When p_s=20atm and R_s=8mm， E_s is about 10.7 J and stable CD does not form at this condition. However when p_0 is slightly

elevated to 1.2atm, which need a little less initiation energy, stable CD can form. Therefore, the source energy needed to ignite successful CD in two-dimensional simulation is a little higher than the critical energy obtained by experiments.

Influence of p_s, T_s and R_s on the formation of CD

A lot of simulations with various source energy conditions are performed in this part. And only the results of R_s=10mm and 20mm are listed in Fig 2 for simplification. As shown in Fig 2, only high p_s and T_s can lead to successful ignition, when R_s is 10mm. As R_s increases, the lower limits of p_s and T_s decrease. And when R_s=20mm, CD can be ignited directly even at p_s=30atm and T_s=1500K. However, the combination of ps and Ts is not arbitrary even when both of them are high. From the chart, it also can be seen that the lower limit of p_s increases with T_s. For example, the lower limit of p_s increases from 30atm to 70atm when T_s is 2000K and 3000K, respectively.
As a whole, R_s is the dominating factor that causes the failure of CD initiation when it is small. And the combination of p_s and T_s becomes more important as R_s increases. Both of them have upper and lower limits in certain cases.

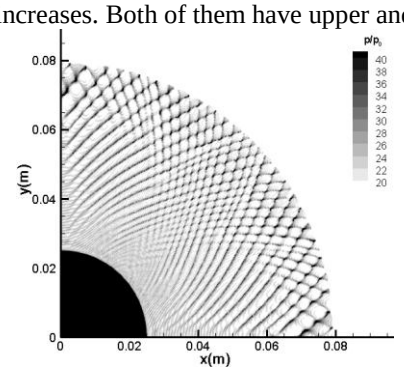

Fig.1. Maximum pressure history when p_s=50atm, T_s=2000K and R_s=25mm within 21.5μs

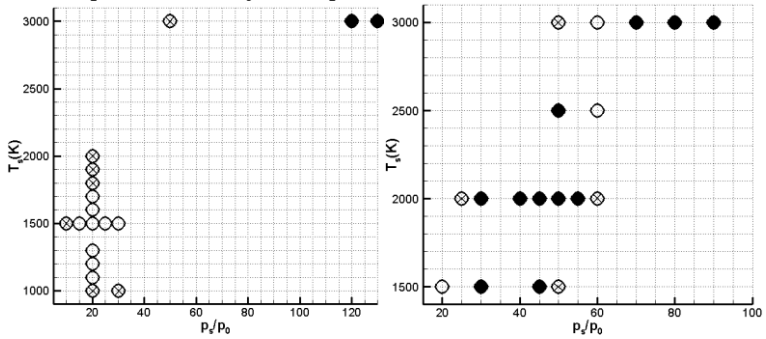

Fig.2. The overall results of all simulation cases with various p_s and T_s at R_s=10mm (left) and 20mm (right); solid circle-successful attempts; circle with fork-failed attempts; blank circle-attempts generating uneven transverse waves.

CONCLUSIONS

In this paper two-dimensional simulations of CD expending in unconfined conditions are performed. The validation of numerical method is discussed to ensure that it can reproduce the folwfieds of CD. Through detailed analysis, it can be summarized as follows: (1) transverse waves must distribute uniformly at the detonation front for successful CD; (2) the critical energy in two-dimensional simulation is higher than the critical energy obtained by experiments; (3) when R_s is small, it is the dominating factor that causes the failure of CD initiation; (4) it is not the truth that the higher the p_s and T_s are, the easier successful ignition becomes. The combination of p_s and T_s must be in proper range.

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