The energy distribution characteristics of a cylindrical cased charge with two end caps

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Abstract. The energy distribution characteristics are the key parameters for analysing the energy distribution of the cylindrical cased charge and improving the damage efficiency of the warhead. To investigate the initial velocities from a cylindrical cased charge detonated at the point on the axis, the flash X-ray radiography system was used to test the velocities of the end caps, and the influence of the axial position of the detonation point was further studied by simulation. The experimental results show that when the thickness of the end cap is equal to that of the casing and the ratio of length to diameter is 3, the velocity of the front end cap is 0.53 times that of the rear end cap. The simulation results show that the initial velocities and energy distribution are affected by the height from the detonation point to the end, and the conversion efficiency of the explosive energy can be increased by adjusting the detonation height and the charge length.

Keywords. Cylindrical cased explosive; Energy distribution; Numerical simulation; X-ray radiography;

1. Introduction

In the past decades, the explosion of cylindrical cased charge has been widely studied by researchers. The cylindrical warhead simplified to an infinitely long cylindrical cased charge was studied by Gurney [1], and energy balance was applied to establish a model for calculating the initial velocity of an expanding cylindrical casing. On the other hand, Baum and Stanyukovich [2] used momentum balance and ignored the rapture of casing during the explosion to find another way to calculate the initial velocity of the cylindrical casing. These models were widely used until the non-uniform fragment velocity caused by “edge effects” was found in the experiments [3]. Thus,
Zulkoski [4], Charron [5], and Huang [6] proposed the non-uniform theories for calculating the casing velocity, respectively. However, the effect of the end cap that can suppress the “edge effect” is rarely studied.

It is reported that the end cap can effectively inhibit the generation of axial rarefaction waves at both ends [7], and the results of the experiment [8] suggested that end caps increased the fragment velocity close to the detonation end by 27% and that close to the non-detonation end by 16%. But the velocity of the end cap and the distribution of explosive energy when the end cap is added are also unclear. The experiment and the numerical simulation were conducted to clarify the initial velocities and the distribution of explosive energy, and both the ratio of length to diameter and the location of the initiation point have been discussed in this paper.

2. Numerical simulation

2.1. Numerical model

A numerical model was developed using the Smoothed Particle Hydrodynamics (SPH) method to discretise the geometry. The SPH method is particular interest for the prediction of fragmentation and fracture at high strain rate in metals as they can deal with large deformations, and propagation, bifurcation and joining of cracks, which has been widely used to simulate the explosion of a cylindrical cased charge [8-10].

The specimen consists of three parts, the explosive, the end cap, and the casing. The Composition B (Comp. B) was adopted in the experiments as the material of the explosive charge, which was modelled using a high-explosive burn model with a JWL equation-of-state. The parameters of Comp. B are listed in Table 1. The AISI 1045 steel was adopted in the experiments as the material of the casing and the end caps, which was modelled using a Johnson-Cook model. The parameters of AISI 1045 steel are listed in Table 2. To calculate the results efficiently and accurately, a 1/4 symmetrical model of the cylindrical cased charge was established with the SPH method in Autodyn. It is reported that the particle size of 0.3mm/0.4mm has good agreement with the experiment result when the diameter of the specimen is about 30mm [11], so the particle size of this model was set to 0.3mm. The numerical model is shown in Fig. 1, where \( L \) is the length of the charge, \( d \) is the inner diameter of the casing, \( D \) is the outer diameter of the casing, and \( \delta \) is the thickness of the end caps. There are three gauge points located on the centre of the end caps and the middle of the casing to record the history of the local velocity (see the red points in Fig. 1), and the detonation point is on the axis of the cylinder.

| Detonation velocity (m/s) | C-J pressure (GPa) | \( c_1 \) (GPa) | \( c_2 \) (GPa) | \( r_1 \) | \( r_2 \) | \( \omega \) |
|---------------------------|-------------------|-----------------|-----------------|----------|----------|--------|
| 7980                      | 29                | 542             | 7.68            | 4.2      | 1.1      | 0.24   |

| \( A \) (GPa) | \( B \) (GPa) | \( n \) | \( C \) | \( m \) | \( T_m \) (K) |
|--------------|--------------|--------|-------|-------|----------|
| 7980         | 29           | 542    | 7.68  | 4.2   | 1.1      |
2.2. Experimental validation

The specimen (\( L = 75\text{mm}, \ d = 25\text{mm}, \ D = 31\text{mm}, \ \delta = 3\text{mm} \)) was tested by flash X-ray radiography system to acquire the velocities of the end caps and the casing, and the schematic view of the experimental setup is shown in Fig. 2. The profiles of the casing and the end caps were recorded on the films at two different times and the displacements were scaled and measured. Then the velocities were calculated by \( V_i = \Delta l_i / (t_2 - t_1) \) (see Fig. 3). On the other hand, the velocity histories were recorded by three gauge points located on the end caps and the casing, and the velocities at \(30\mu\text{s} \) were adopted as the final results. The simulation results and experimental results are listed in Table 3.

From the comparison results in Table 3, it can be seen that the relative error of the front end cap velocity between the simulation and the experiment is 8.75%, and that of the rear end cap velocity between the simulation and the experiment is 1.33%, and that of the middle casing velocity between the simulation and the experiment is 3.58%. The comparison shows a good agreement between the experiment and numerical simulation.

| Results     | Velocity of the front end cap (m/s) | Velocity of the rear end cap (m/s) | Velocity of the middle casing (m/s) |
|-------------|-------------------------------------|-----------------------------------|------------------------------------|
| Simulation  | 957                                 | 1628                              | 1429                               |
| Experiment  | 880                                 | 1650                              | 1482                               |
| Relative error | 8.75%                         | 1.33%                             | 3.58%                             |
3. Simulations on the effect of the detonation point

Numerical simulations with three different detonation points were conducted. As shown in Table 4, these simulations use the same parameters except $H/d$. To clarify the effect of $H$ on the part velocity and the energy distribution, three different $H/d$ are adopted in the simulations, where $H$ is the height from the front end cap to the detonation point (see Fig. 1).

The simulation results on the effect of the detonation point are shown in Fig. 4 and Fig. 5. Fig. 4 shows the velocity history of Gauge 1# and Gauge 3# in the simulations which were detonated at different points. As the height from the detonation point to the front end cap increases, the initial velocity of the front end cap increases, and the initial velocity of the rear end cap decreases. Fig. 5 shows the kinetic energy of the casing and the end caps in these simulations. As the height from the detonation point to the front end cap increases, the kinetic energy of these two end caps rise, and the energy of the casing decreases. These results indicate that the height $H$ can adjust the velocity of the end caps and the energy distribution of the explosion to enhance the power of the fragment.

Table 4
Parameters of the configurations in the numerical models.

| Simulation ID | Thickness of end caps ($δ$, mm) | Inner diameter of casing ($d$, mm) | Out diameter of casing ($D$, mm) | $H/d$ | $L/d$ |
|---------------|--------------------------------|----------------------------------|--------------------------------|-------|-------|
| SPH-1         | 3                              | 31                               | 3                              | 0     | 3     |
| SPH-2         | 0.75                           | 31                               | 3                              | 0.75  | 3     |
| SPH-3         | 1.5                            | 31                               | 3                              | 1.5   | 3     |

Fig. 4. The velocity history of Gauge 1# and Gauge 3#.

Fig. 5. The kinetic energy of the casing and the end caps.

4. Simulations on the effect of the charge length

Numerical simulations with three different charge length were conducted. As shown in Table 4, these simulations use the same parameters except $L/d$. To clarify the effect of $L$ on the part velocity and the energy distribution, three different $L/d$ are adopted in the simulations, where $L$ is the length of charge (see Fig. 1).

The simulation results from the models with different charge length are shown in Fig. 6 and Fig. 7. Fig. 6 shows the velocity history of Gauge 1# and Gauge 3# in the simulations with different charge
length. As can be seen, there is no difference in the velocity histories of the front end caps in these simulations, and the velocity histories of the rear end caps are consistent with the results shown in Fig. 4. Fig. 7 shows the kinetic energy of the casing and the end caps in these simulations. It can be seen that as the length of charge decreases, the kinetic energy of the casing decreases considerably, and the kinetic energy of the end caps is almost unchanged. To summarise, the proportion of casing kinetic energy in explosive energy decreases. These results indicate that if the height $H$ is constant, the charge length $H$ has a negligible effect on the kinetic energy and velocity of the end caps, but the charge length determines the conversion efficiency between explosive and the kinetic energy of casing.

### Table 5
Parameters of the configurations in the numerical models.

| Simulation ID | Thickness of end caps ($\delta$, mm) | Inner diameter of casing ($d$, mm) | Out diameter of casing ($D$, mm) | $H/d$ | $L/d$ |
|---------------|-------------------------------------|----------------------------------|-------------------------------|------|------|
| SPH-1         | 3                                   | 25                               | 31                            | 0    | 3    |
| SPH-4         | 3                                   | 25                               | 31                            | 0    | 2.25 |
| SPH-5         | 0                                   | 1                                | 31                            | 0    | 1.5  |

**Fig. 6.** The velocity history of Gauge 1# and Gauge 3#.

**Fig. 7.** The kinetic energy of the casing and the end caps.

### 5. Conclusions

The simulation and the experiment were conducted to investigate the initial velocities and the energy distribution of the explosive. The results show that the height from the detonation point to the end cap can significantly affect the velocity and kinetic energy of the end cap. It also can be concluded that the warhead has a higher conversion efficiency from explosive energy to the casing kinetic energy when the charge was detonated at one end. And as the value of $L/d$ decreases, there is a significant reduction in conversion efficiency from explosive energy to the casing kinetic energy.

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