Formation Regularity of Annular Shaped Charge Jet by Numerical Simulation

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Abstract. Formation process of an annular-shpere liner driven by shaped charge has been studied using AUTODYN numerical simulation software. Research works of factors, including length to diameter ratio of charge, detonation radius and distance between liner and shell, that affect the jet head velocity, deflection angle, and head diameter have been implemented. The results show that the liner driven by shaped charge initiated annularly will be shaped into a annular jet which can form a large-diameter hole on the target, while the liner forms a converged jet when shaped charge is centrally initiated. As the ratio and the initiation radius increase, the jet diverges; as the distance between the liner and the shell increases, the jet converges.

1. Introduction

Shaped charge is widely used in military and civil fields. The traditional shaped charge always reach a good penetration depth, Jet driven by traditional shaped charge can penetrate deeply on a target, forming a small diameter hole on it. But small crater diameter of hole. However, the demand for large diameter hole technology has increased in practical applications. And an annular liner can be shaped into a cylinder jet which can form a large diameter hole on the target after driving by shaped charge. Some scholars have carried out research on annular shaped charge. There are two types of annular shaped charge structures: the hollow annular shaped charge and the integral annular shaped charge. The hollow annular shaped charge has a small charge and a large surface area. The low utilization rate of explosives affects the penetration ability of the annular jet. In 1978, Leidel [1] designed a simple integral annular shaped charge; In 2001, Meister et al.[2] studied the influence of the liner material on the formation of annular jet theoretically and numerically; In 2008, Li Pengfei et al. [3] implemented numerical simulations and tests on two types of annular-cone and annular-sphere liner. Compared with the annular-cone, the annular jet formed by the annular-sphere liner was more stable. in 2014, Xie Jun et al.[4] studied the influence factors such as the liner of material, thickness and angle on the formation process of annular-cone liner. In 2016, Tong Zongbao et al.[5] used LS-DYNA to analyze the formation process of annular-cone shaped charge. In 2018, Xu Wenlong et al. [6,7] carried out numerical simulations and tests on the shaped charge structure of the annular-sphere liner with a length-to-diameter ratio of 1.8 and systematically studied the (effects caused by) charge diameter, shell thickness, and the liner of structural parameters on annular jet forming process. Based on the integral annular-sphere shaped charge structure, the effects of the length to diameter ratio of the charge, the detonation radius, the distance between the liner and the shell on the three parameters of the jet head velocity, deflection angle and head diameter were analyzed numerically.
2. Numerical Simulation

2.1. Simulation Model

In this paper, a two dimensional axisymmetric model, consisting of a shell, charge, liner and air, is established using AUTODYN software. This consists of a shell, a charge, a liner, and an air. The finite element model is shown in Figure 1, where \( D \) is the charge diameter, \( L \) is the length of the charge, \( a \) is the distance between the liner and the shell. The Euler method is used and the “Flow-Out” boundary condition is added, as shown in Figure 2.

![Figure 1. finite element model.](image1)

![Figure 2. Schematic diagram of parameter a.](image2)

2.2. Material Model

The materials used in this work consist of air, explosive, shell, and liner. The explosive is JH-2, and the JWL equation of state (EOS) is selected to describe the propagation process of the explosive product. The liner material is copper, the shell material is made of steel, the EOS of them is shock model and the strength model is Johnson-Cook [8]. The EOS of the air is the Ideal Gas state. Specific parameters of each material are shown in Tables 1 and 2.

| Material | \( \rho \) (g/cm\(^3\)) | \( A \) (MPa) | \( B \) (MPa) | \( n \) | \( C \) | \( m \) | \( T_m \) (K) |
|----------|-----------------|--------------|--------------|------|------|------|------------|
| Copper   | 8.93            | 90           | 292          | 0.31 | 0.025| 1.09 | 1356       |
| Stell    | 7.896           | 350          | 275          | 0.36 | 0.022| 1.0  | 1811       |

| Material | \( \rho \) (g/cm\(^3\)) | \( D \) (m/s) | \( A \) | \( B \) | \( R_1 \) | \( R_2 \) | \( \omega \) |
|----------|-----------------|--------------|------|------|----------|----------|--------|
| JH-2     | 1.722           | 8425         | 55.8 | 6.9  | 4.1      | 1.4      | 0.4    |

3. Results and Analysis

3.1. Effect of length-to-diameter ratio of charge on annular jet forming

The angle between the jet head velocity and the horizontal direction is defined as deflection angle \( \theta \) (the outward deflection is positive and the inward deflection is negative), as shown in Figure 3, where \( v \) (m/s) is the jet head velocity, \( d \) (mm) is the diameter of the head. In order to ensure the consistency of the data, the data collection time of each working condition in this paper is 0.5D.
Figure 3. Schematic diagram of parameter definition.

Figure 4 shows the jet forming conditions of the annular shaped charge structures with different length-to-diameter ratios in the central detonation and annular detonation (r=1/2D). Figure 5 shows the variation rule of the jet parameter with the length-to-diameter ratios.

From Figure 5, it can be seen that under the same initiation mode, as the L/D increases, the amount of charge increases, the head velocity gradually increases, the deflection angle and the head diameter also gradually increased and eventually flattened. When the L/D increase to more than 1.2, the increase of the explosive mass has little effect on the head velocity, deflection angle and head diameter. Therefore, a appropriate ratio of length-to-diameter can improve the energy utilization rate of the explosive without reducing the penetration power. At the same L/D, the mass of the annular jet formed by the central initiation is uniform, and the head has a significant inward deflection. The parameters of the annular jet formed by the annular initiation are higher than the central initiation. Compared with the central detonation, the annular initiation is more effective to the formation of a good annular jet with a larger penetration diameter.
3.2. Influence of detonation radius on annular jet forming

According to the research results in Section 3.1, the formation of annular shaped charge structures with the L/D=1.2 with different initiation radius is simulated. Figure 6 shows the jet forming conditions of the annular shaped charge structures with different initiation radius. And Figure 7 is a diagram showing the variation rule of the jet parameter with the initiation radius.

![Figure 6](image)

**Figure 6.** The jet forming conditions with different initiation radius (L/D=1.2, a=3.5mm)

![Figure 7](image)

**Figure 7.** The variation rule of the jet parameter with the initiation radius.

From Figure 7, it can be seen that within the scope of the study, as the initiation radius increases, the head velocity, deflection angle, and head diameter of the annular jet gradually increase; When the radius is 1/2D, the deflection angle approaches 0 °. At this time, the penetrating gesture of the annular jet is the best. By changing the initiation radius, the annular jet of different calibers can be formed to meet the actual needs.

3.3. Influence of the distance between the liner and the shell on the annular jet forming

Figure 8 shows the jet forming conditions of the annular shaped charge structures with different distance between the liner and the shell in the annular detonation (r=1/2D). Figure 9 is a diagram
showing the variation rule of the jet parameter with the distance between the liner and the shell.

![Figure 8](image)

**Figure 8.** the jet forming conditions with different distance between the liner and the shell (L/D=1.2, r=1/2D).

![Figure 9](image)

**Figure 9.** the variation rule of the jet parameter with the distance between the liner and the shell.

It can be seen from Figure 9 that as the distance between the liner and the shell increases, the distance between the two hemispherical symmetry axes on the plane of symmetry of the liner decreases. The head velocity of the annular jet gradually increases, the head diameter decreases. As the amount of explosive on the outer side of the liner increases, the jet converges and a negative deflection angle is formed.

### 4. Conclusions

In this paper, a numerical simulation model of the annular-sphere shaped charge is established, and numerical simulation research is carried out to study the forming rule of the annular jet. The effect rules of three factors including the length to diameter ratio of the charge, the detonation radius, and the distance between the liner and the shell on the head velocity, deflection angle, and head diameter of the annular jet were obtained. The following conclusions can be drawn:

1. The head velocity of the jet is directly proportional to the three factors, including the deflection angle, the head diameter is proportional to the L/D and the r, and is inversely proportional to the distance between the liner and the shell.
2. When L/D is small, the jet is more likely to be shaped into a converged jet compared to the situation driven by centrally initiated shaped charge. The above parameters can be adjusted according to requirements to obtain an ideal annular jet.

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