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Jet Forming Characteristics of Shaped Charge with Reactive Material Composite Liner

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Abstract. The influence of metal liner material, the ratio of inner and outer liner diameter, and the cone angle of composite liner on the forming characteristics of the reactive composite jet were studied by using the finite element software AUTODYN. The numerical simulations show that with the increase of the inner liner diameter, the tip velocity of the composite jet decreases, and the following situation of the reactive material becomes worse. With the increase of the cone angle of the composite liner, the continuity of the composite jet becomes better, but the jet tip velocity decreases. With the increase of the material density of the metal liner, the velocity of the composite jet tip decreases, but the continuity of the jet becomes better.

Keywords: shaped charge; reactive material; composite liner; forming characteristics; numerical simulation.

1. Introduction

The shaped charge with reactive material liner is a research hotspot in recent years [1]. Baker et al. studied the jet-forming behavior of shaped charge with reactive liner, and studied the enhanced damage effect of reactive material jet on the airport runway and reinforced concrete by blasting through static blasting experiment [2]. A. S. Daniels et al. studied the damaging effect of reactive material jet on concrete and asphalt runway [3]. Domestic scholars have also carried out a lot of research work on the reactive liner-shaped charge technology, including the jet forming characteristics of PTFE/Al reactive-shaped charge [4], the terminal damage effect of reactive liner-shaped charge on multi-layer concrete target [5], the explosion damage effect of reactive jet on multilayer interval aluminum target [6], and characteristics of explosion overpressure of the reactive material jet in steel target [7].

However, at present, the material used for the shaped charge liner is mainly conventional PTFE/Al reactive material. The low ductility of this reactive material causes that although the reactive jet has a strong internal explosion damaging effect, its penetration ability is insufficient, and it is difficult to effectively use the combined damage of kinetic energy and chemical energy to the aarmoredtarget. To improve the penetration ability, a composite liner composed of reactive material liner and metal liner has attracted increasing attention from domestic and foreign researchers [8]. The shaped charge with composite liner is to add a layer of metal liner on the inside of the reactive material liner. Under the action of the shaped charge, the inner metal liner forms a high-velocity front jet to cause a deep penetration depth to the target. Then the outer reactive material liner follows and produces a deflagration effect within the target, to study the structural damage to the target or the aftereffect to enhance the damaging effect [9]. At present, there is little research on the jet forming of shaped charges with reactive material composite liner (RM-CL).

In these cases, the following aspects are researched in this paper. Firstly, the numerical method of shapes charge with RM-CL is established based on AUTODYN-2D code. Then, a series of simulations are carried out to discuss the influence of the liner diameter ratio and cone angle on forming characteristics of the reactive composite jet. Finally, the influence of several metal materials on jet-forming characteristics is compared.

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2. Material Model and Numerical Method

2.1 Material Model

To study the jet-forming characteristics of the shaped charge with RM-CL, the structure of the shaped charge remains unchanged. The shaped charge is mainly composed of the composite liner, case, and explosive. The composite liner is composed of a metal liner and a reactive material liner. The metal liner materials selected in this paper are Al-2024, titanium, Steel S-7, Cu-OFHC, and tantalum. The reactive material is PTFE and Al, and the mass ratio is 73.5 % and 26.5 %. The material of the case is Steel 1006, and its thickness is 3mm. The parameters of each metal material are listed in Table 1, and the data are taken from the material library of AUTODYN. The main parameters of reactive material are from the literature of Raftenberg [10], as listed in Table 2. The main material parameters of 8701 are listed in Table 3.

Table 1. Material parameters of metals.

Material	ρ (g.cm^{-3})	C_1(m/s)	S_1
Al-2024	2.785	5328	1.338
Titanium	4.528	5220	0.767
Steel S-7	7.75	4569	1.49
Steel 1006	7.896	4569	1.49
Cu-OFHC	8.96	3940	1.489
Tantalum	16.654	3414	1.201

Table 2. Material parameters of the reactive liner.

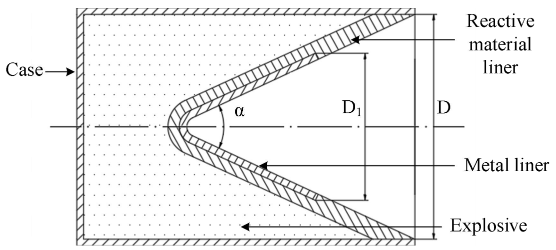
Material	ρ (kg/m^3)	G (GPa)	A (MPa)	B (MPa)	n	C	m	T_m (K)	T_{room} (K)	Γ	c_0 (m/s)	S
Reactive liner	2.27	0.666	8.044	250.6	1.8	0.4	1	500	294	0.9	1450	2.2584

Table 3. Material parameters of 8701.

Material	ρ (kg/m^3)	G (GPa)	A (MPa)	B (MPa)	n	C	m	T_m (K)	T_{room} (K)	Γ	c_0 (m/s)	S
Reactive liner	2.27	0.666	8.044	250.6	1.8	0.4	1	500	294	0.9	1450	2.2584

2.2 Numerical Method

The AUTODYN-2D software platform is used for numerical simulations. The structure of the shaped charge with RM-CL is shown in Figure 1. The diameter of the shaped charge is 100 mm, the length of the shaped charge is 150 mm, and the thickness of the case is 3 mm. The metal liner and reactive material liner are combined as shown in Figure 1, the diameter of metal liner D1 is smaller than the diameter of reactive material liner D. The same cone angle size is used, and the total thickness of the composite liner is 8 mm. In numerical simulations, the Euler algorithm is used for the case, reactive material liner, metal liner, and explosive. To ensure the accuracy and efficiency of the simulation, the grid size is 0.25 mm × 0.25 mm, using the central detonation method and adding flow-out boundary conditions in the simulation to ensure the jet formation. The numerical simulation model of the jet-forming process of composite liner-shaped charge is shown in Figure 2.



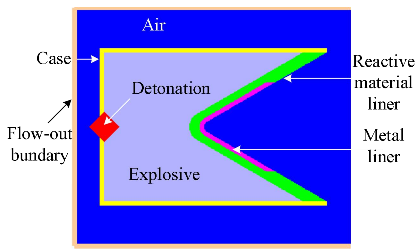


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Figure 1. Structure of shaped charge. **Figure 2.** Numerical simulation model.

3. Analysis of Jet-forming Characteristics

3.1 Influence of the Liner Diameter Ratio D1/D

Figure 3 and Figure 4 show the simulated results of jet forming and jet tip velocity with different inner diameter ratios when α = 50 ° and 80 °. It can be seen from the figures that under the condition of constant cone angle, when D1/D increases from 0.6 to 0.7, the tip velocity of the jet decreases significantly. When D1/D is greater than 0.8, with the increase of the ratio, the reactive material no longer participates in the forming process of the jet tip, so the tip velocity of the jet is almost unchanged. With the increase of the inner copper liner diameter, the jet breaking time is prolonged, and the forming performance is better. However, when the ratio is larger than 0.8, the proportion of reactive materials is small and concentrated in the slug, which is not conducive to the following of reactive materials and affects the penetration effect. When the ratio is smaller than 0.7, the reactive material accounts for a large proportion and covers the front section of the jet, but the metal core is too thin to cause large penetration. In general, the inner diameter ratio should not be too large or too small, and it is generally better to take 0.7 ~ 0.8.

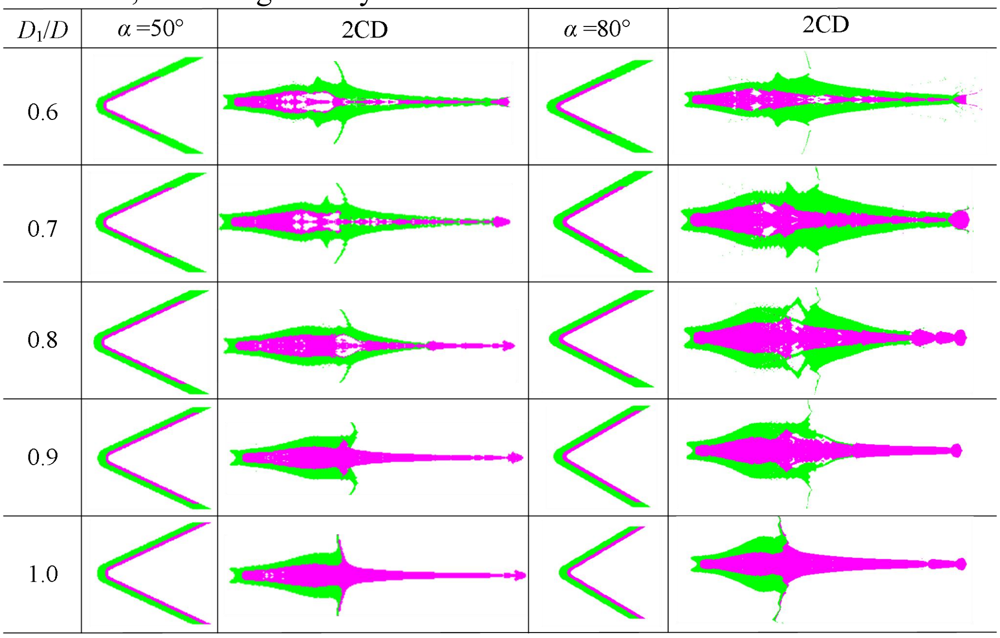
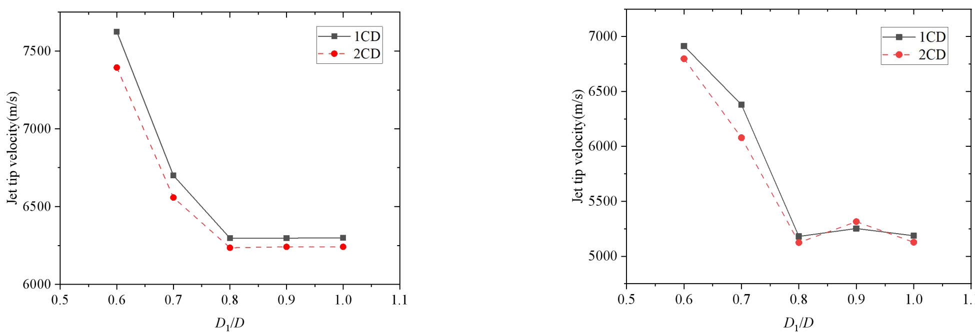


Figure 3. Simulated results of composite jet forming with different D_1/D when α = 50° and 80°.



(a) 50° (b) 80°

Figure 4. The tip velocity of composite jet with different D_1/D when α = 50 ° and 80 °.

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3.2 Influence of the Liner Cone Angle α

Figure 5 and Figure 6 show the simulated results of jet forming and jet tip velocity with different cone angles when D1/D = 0.7 and 0.8. It can be seen from the figures that the cone angle mainly affects the forming of the inner liner when D1/D is constant. With the increase of the cone angle, the jet velocity decreases as a whole. When the cone angle is smaller than 60 °, the jet is thin and long, and the jet tip necks and breaks seriously, which is not conducive to the penetration of the jet to the target. When the cone angle increases to 80° , the composite jet becomes shorter and thicker, and the formed jet is more stable, but the tip velocity of the jet is smaller. Therefore, the cone angle should not be too large or too small, generally 60 °~70 °.

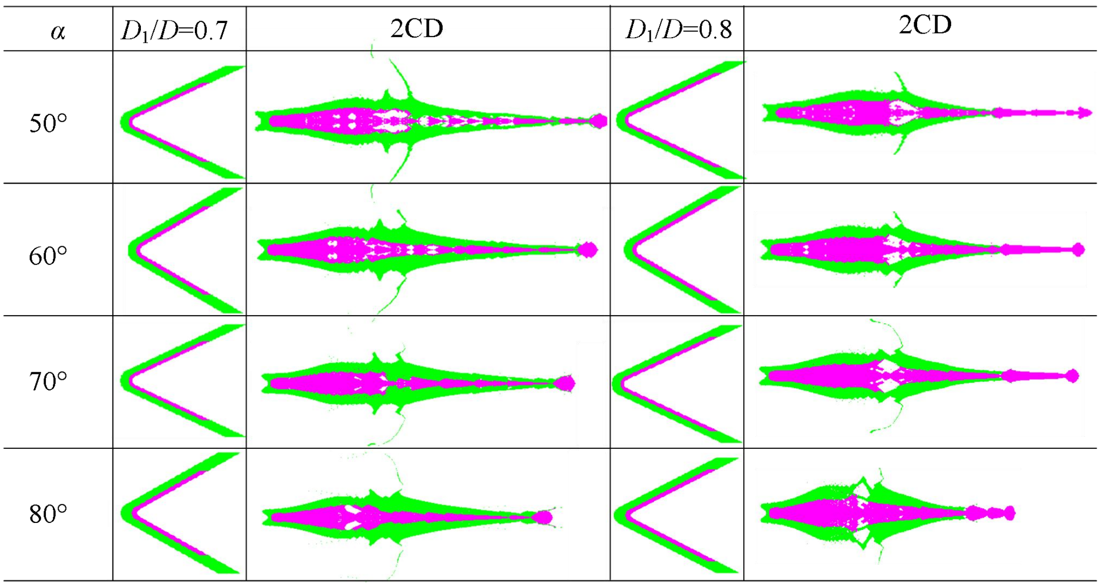
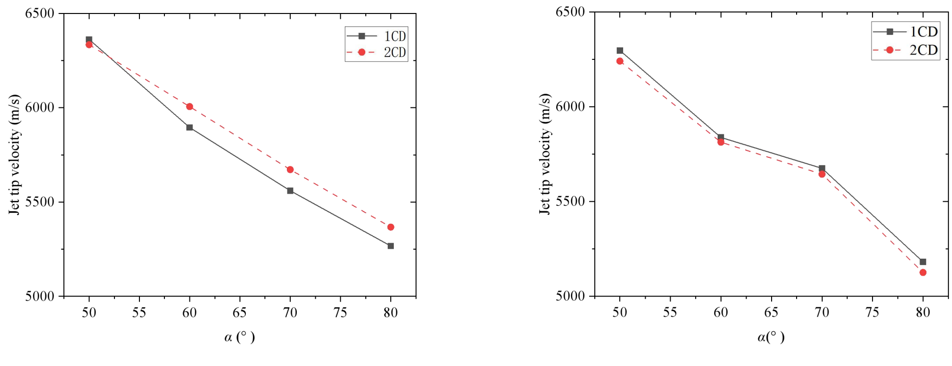


Figure 5. Simulated results of composite jet forming with different cone angles when D_1/D = 0.7 and 0.8.



(a) 0.7 (b) 0.8

Figure 6. The tip velocity of composite jet with different cone angles when D_1/D = 0.7 and 0.8.

3.3 Influence of the Metal Liner Material

Figure 7 shows the simulated results of jet forming with different metal liner materials when D1/D = 0.8 and α = 60°. Figure 8 shows the tip velocity and length of composite jets with different metal liner materials. By comparing several different materials, it can be seen that the tip velocity of the jet decreases with the increase of the density of the inner liner. In addition, the type of inner liner material has no significant effect on the jet length.

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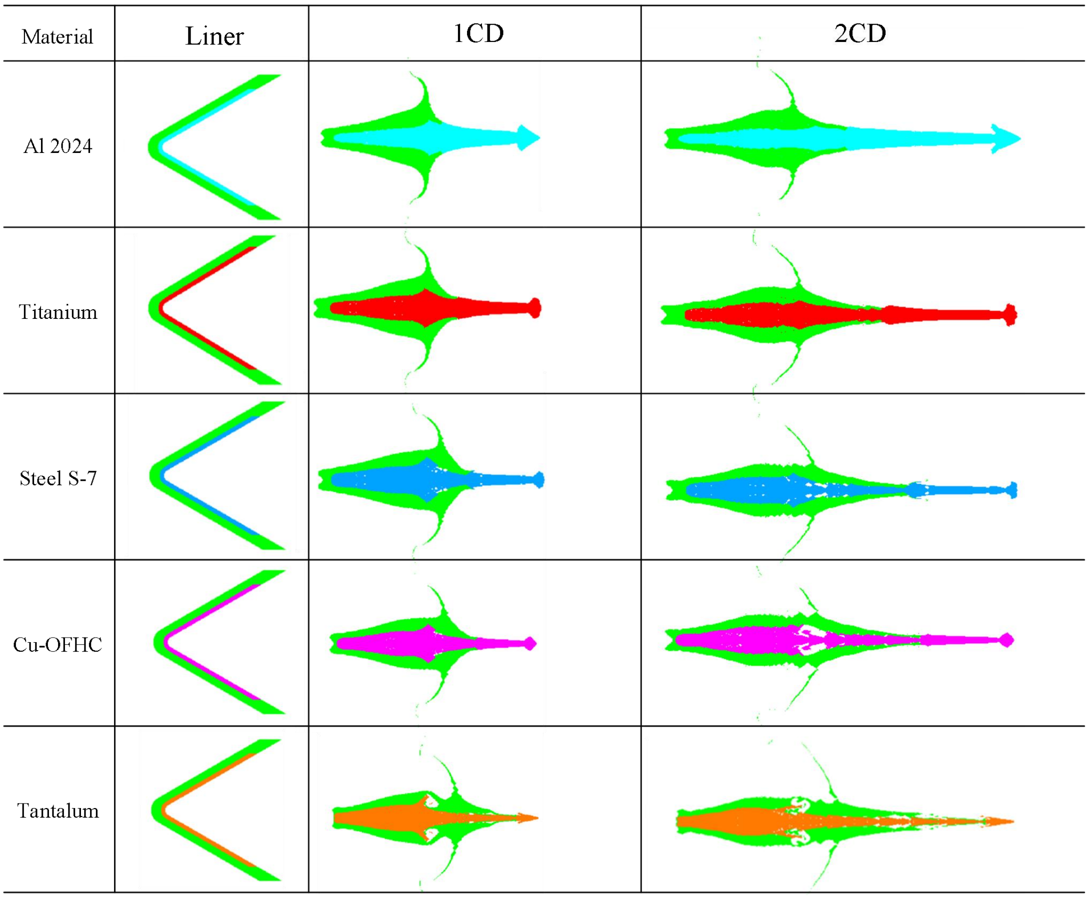
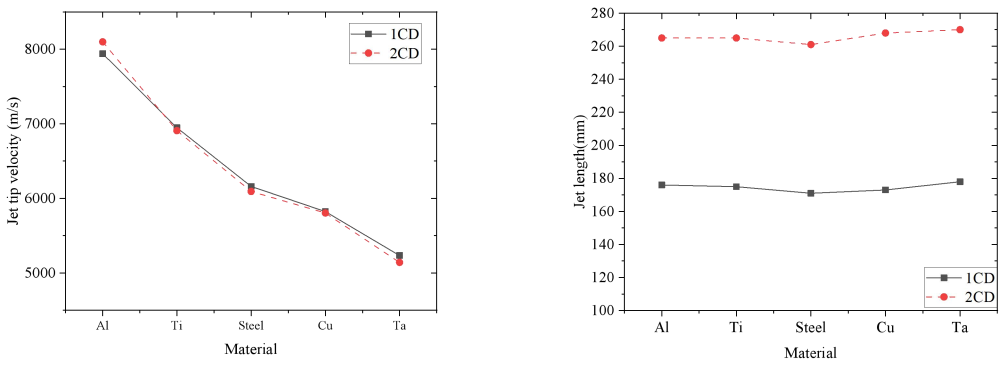


Figure 7. Simulated results of composite jet forming with different metal liner materials.



(a) Jet tip velocity (b) Jet length

Figure 8. Tip velocity and length of composite jet with different metal liner materials.

By observing the jet shape, it can be found that there are pores in the jet of steel, copper, and tantalum liner, and the volume of pores increases with the increase of material density. When the material density of the inner liner is too high like tantalum, pores in the forepart of the jet make the reactive material unable to cover the metal jet, resulting in a poor situation of the following reactive material when the composite jet penetrates. Except it, the pores of steel and copper liner are mainly in the slug, which has little influence on the penetration ability of the jet. Metal jets with a low density such as aluminium and titanium are not covered basically by reactive material. With the increase of metal material density, the difference in pressing speed between the inner and outer liner increases, which makes the coating of reactive material gradually improve.

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4. Conclusion

In this paper, the jet-forming characteristics of the shaped charge with reactive material composite liner are studied. The main conclusions are as follows:

(1) When the liner diameter ratio is less than 0.8, the tip velocity of the composite jet decreases with the increase of the ratio. When the ratio is larger than 0.8, the tip velocity of the composite jet is unchanged basically. When the ratio is 0.7 and 0.8, the composite jet has higher tip velocity, and the following condition of reactive material is also better.

(2) When the cone angle of the composite liner is smaller than 60 °, the tip velocity of the composite jet is higher, but the jet fracture seriously. When the liner cone angle is larger than 70 °, the composite jet is with good continuity, but the tip velocity of the jet is lower. When the liner cone angle is 60 ° and 70 °, the comprehensive performance of the jet is better.

(3) Tip velocity of the jet decreases with the increase of the inner liner density, while the coverage of reactive material is gradually improved. The composite liners using steel or copper can consider both velocity and the following conditions of reactive material.

5. Acknowledgments

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