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Study on formation characteristics of the shaped charge with an untypical reactive material composite liner

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Abstract. The shaped charge with reactive material composite liner could not only has good penetration capability, but also has a strong internal explosion damage effect. The influence of the ratio of reactive material liner thickness, the ratio of reactive material liner height and the cone angle of composite liner on the forming characteristics of the untypical reactive material composite jet was studied by using the finite element software AUTODYN. The numerical simulations show that with the increases of the ratio of reactive material liner thickness and the ratio of reactive material liner height, the head velocity of the composite jet increases, but the distribution of titanium in the jet becomes unfavorable for penetration. With the increase of the composite liner cone angle, the diameter of the composite jet increases, but the head velocity of jet decreases.

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

1. Introduction

Reactive composite materials made from the mixture of fluoropolymer binder and metal materials (such as PTFE/Al, PTFE/Al/W, THV/Al et al) have attracted extensive attention in recent years [1-3]. Generally, the class of reactive composite materials can be cold pressed and sintered to be prepared into various shapes. The conical liner prepared by the reactive composite materials can produce a good damage effect when it applied to the shaped charge. A. S. Daniels studied the damage effect of reactive material (RM) jet penetrating concrete and asphalt runway [2]. Byun Gyeongjun investigated the deposition state and self-propagating high-temperature synthesis reaction behavior of the Al-Ni deposit [3]. Domestic scholars have also done a lot of work for it, including, the corresponding penetration performance of PTFE high-density RM-liner [4], the enhanced lethality of RM-jet penetrating concrete target [5], the formation process of RM-liner shaped charge adopted cross-scale discretization method [6], etc.

However, limited by the strength of existing RMs, the penetration ability of RM-jet is weaker than traditional metal jet, which affects its further role in blasting damage. Therefore, it is proposed to combine the RM-liner with the metal liner to form a composite shaped charge liner, which gives consideration to both the kinetic energy penetration capability of the metal jet and the chemical energy burst damage of the RMs. Huang Bing-yu designed an Al/Ni-Cu double layered energetic liner shaped charge structure to improve the penetration depth [7]. Wang HF investigated the penetration enhancement behaviors of the shaped charge with RM- liner against thick steel targets. [8]. At present, the study of reactive composite jet penetrating the steel target is more, but the study on the concrete target is still less. Although the RM- composite liner can have good penetration ability and blasting performance at the same time in theory, it still needs more in-depth research on how to give consideration to both in practical research.

In this paper, a new structure of RM-composite liner is proposed. The upper part of the inner liner, which mainly forms the forepart jet, and the outer liner, which mainly forms the slug, are composed of titanium to improve its penetration ability. The lower part of the inner liner is composed of RMs, so that the RMs can cover the metal jet to enter the hole with the advance. The

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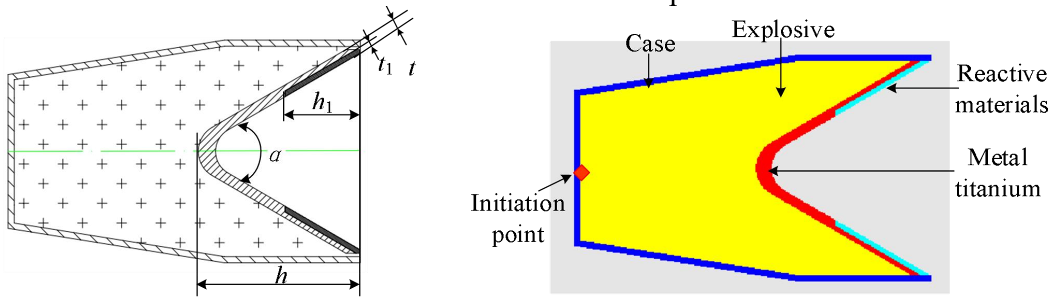
structural parameters of shaped charge are optimized through numerical simulation, so that the composite jet has both strong penetration ability and better RMs following situation.

2. Simulated method and material model

For the sake of studying the forming behavior of the shaped charge with an untypical RM-composite liner, the AUTODYN-2D simulation software platform is used. The schematic diagram and simulation model of the composite liner shaped charge is shown in Fig. 1. The shaped charge is mainly composed of composite liner, explosive and case. The composite liner is made of the metal titanium and the RMs. The charge diameter is 66mm and length is 110mm. The thickness of the case is 2mm. Titanium liner and RM-liner adopt the same cone angle. The total wall thickness of the composite liner is 6mm. The case, composite liner and explosive are filled in Euler algorithm. The detonation mode at the center of the bomb bottom is adopted.



(a) Schematic diagram (b) Simulation model

Figure 1. Structure of the shaped charge with untypical RM composite liner

The explosive is used the high-energy 8701 explosive, and its detonation velocity is about 8315 m/s, and Table 1 shows the main parameters [9,10]. The RMs are composed of 73.5% PTFE and 26.5% Al, and Table 2 shows the main parameters [9,10]. The case material is 2024 Al. The material parameters of metal titanium and 2024 Al case are taken from AUTODYN material library.

Table 1. Material parameters of the 8701 explosive

Material	ρ (g/cm3)	D (km/s)	PCJ (GPa)	e (GPa)	A (GPa)	B (GPa)	R1	R2	ω	v0
Explosive	1.71	8.315	28.6	8.499	524.23	7.678	4.2	1.1	0.34	1.00

Table 2. Material parameters of the RMs

Materials	ρ (kg/m3)	G (GPa)	A (MPa)	B (MPa)	n	C	m	Tm (K)	Troom (K)	Γ	c0 (m/s)	S
Reactive liner	2.270	0.67	8.04	250.6	1.8	0.4	1.03	500	294	0.9	1450	2.26

3. Formation behavior of the untypical composite jet

3.1 Influence of reactive liner thickness ratio

To study the influence of the ratio of RM-liner thickness to total liner wall thickness δ (δ = t1/t) on jet forming characteristics, ensure that the RM-liner height accounts for 0.5 of the total liner height, and the liner cone angle is 60 °, δ select 0.3, 0.5, 0.7 and 0.9 respectively. Under different working conditions, the forming characteristics of composite jet are shown in Fig. 2 (a). With the increase of the δ, the proportion of RMs in the jet gradually increases, and even the first half of the slug changes from titanium to RMs. More quality of RMs is conducive to the blasting damage of the target after the composite jet penetration. However, with the increase of δ, the metal titanium

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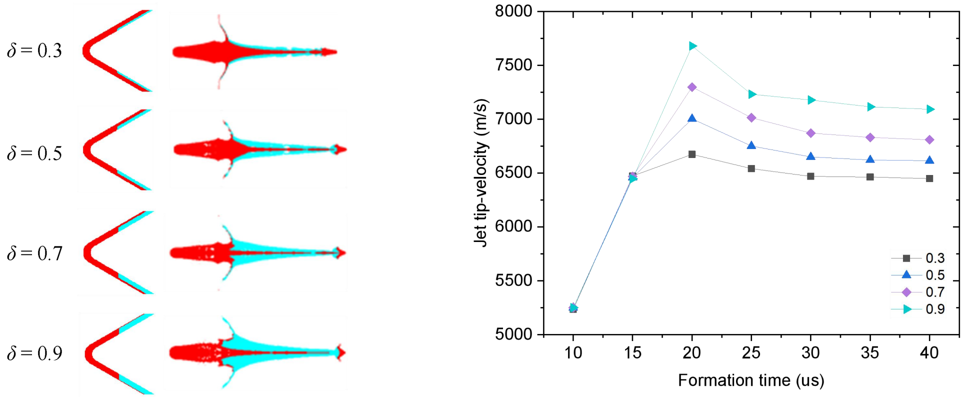
core inside the composite jet is also getting thinner, even no longer continuous, which is not advantageous to the stable penetration ability of the composite jet. In addition, it can be seen that the composite jet length remains basically unchanged with the increase of δ.



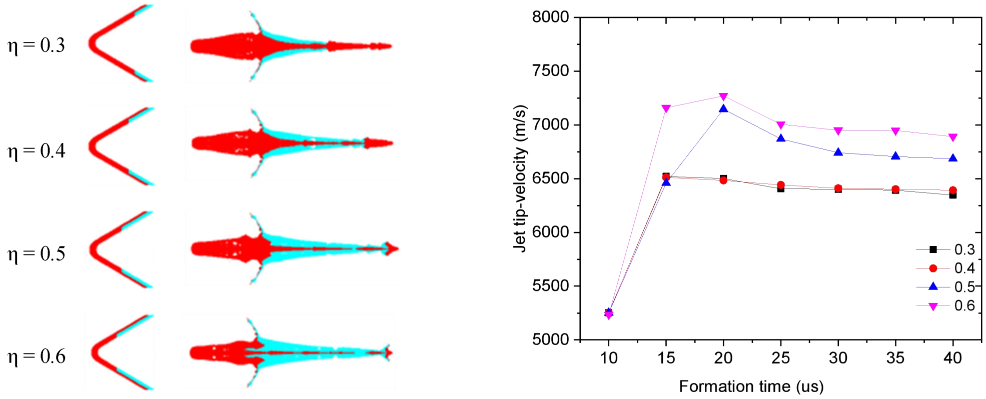
(a) Formation morphology of jet (b) Jet tip-velocity

Figure 2. Variation of jet head velocity and effective jet length with the thickness ratio.

The effect of thickness ratio of RM-liner on the velocity of composite jet head is shown in Fig. 2 (b). With the increase of RM-liner thickness, the jet head velocity increases gradually at the same forming time. When δ = 0.9, the maximum velocity of the composite jet head is about 7680 m/s, and when the jet head at 2 CD, the velocity is about 7090 m/s. However, when δ = 0.3, the velocity of jet head is only 6450 m/s. It is mainly due to the density of RMs is smaller than that of titanium, when the total volume is unchanged, the mass of the composite liner with a large proportion of RM-liner thickness is less, which can achieve a greater pressing velocity under the loading of shaped charge with the same structure. In conclusion, when the ratio of RM-liner thickness is 0.5~0.7, the composite jet head velocity and RMs quality match well.

3.2 Influence of reactive liner height ratio

The ratio of RM-liner height has certain effects on the forming characteristics of composite jet. Select the ratio of RM-liner thickness δ = 0.7, the liner cone angle is 60 °. RM-liner height accounts for the total height of composite liner η (η = h1/h) is 0.3, 0.4, 0.5 and 0.6. Under different working conditions, the forming characteristics of composite jet are shown in Fig. 3 (a). With the increase of the η, the proportion of RMs in the jet gradually increases, but the proportion of titanium metal in the composite jet head gradually decreases until it is basically composed of RMs. According to the jet penetration mechanism, because the density of RMs is lower than that of titanium, the penetration depth of composite jet composed of RMs will also be smaller. In other words, when the η is reasonably large, it is to the prejudice of the penetration of composite jet to the target. In addition, Fig. 3 (a) also shows that the η has little effect on composite jet length.



(a) Formation morphology of jet (b) Jet tip-velocity

Figure 3. Variation of jet head velocity and effective jet length with the height ratio.

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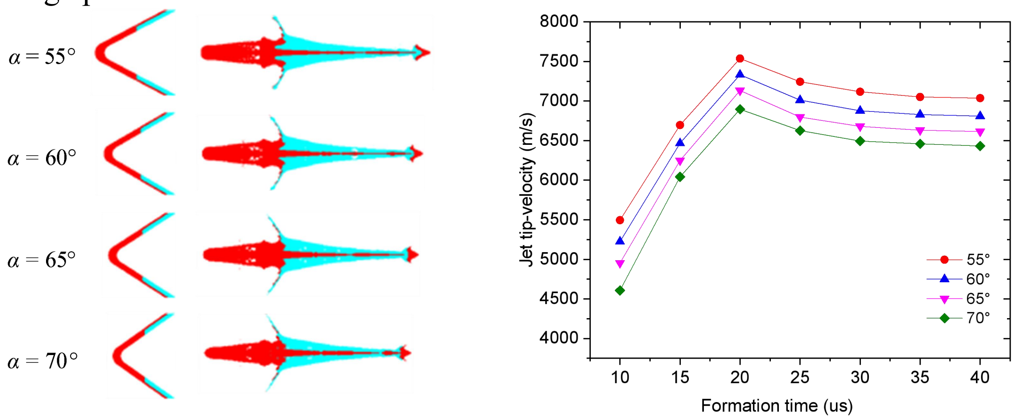
Fig. 3 (b) shows the effect of the η on the velocity of the composite jet head is shown in. It can be found that with the increase of the η, when the jet arrived at 2CD, the velocity of the composite jet head increases from 6350 m/s to 6870 m/s. On the one hand, as the η increases, the total mass of composite liner decreases, resulting in an increase in pressing velocity. On the other hand, in the formation process of composite jet, the detonation wave arrives at the RM-liner section of the composite liner with the height ratio of 0.6 and 0.5 at 15 μs and 20 μs. When the forming time is 25 μs, the detonation wave arrives at the RM liner section of the composite liner with the η of 0.5. According to Fig. 3 (a), the RMs under these two working conditions do not participate in the forming of the composite jet head. And when the forming time is 15 μs, the composite jet head under these two working conditions has been formed, so the formed composite jet head has the same velocity. Considering the head velocity of composite jet and the mass of following RMs, when the η is 0.4~0.5, the composite RM-jet has good comprehensive performance.

3.3 Influence of composite liner cone angle

In order to research on the affecting of the cone angle α of the liner on the jet forming of RM-composite liner shaped charge, the α of the liner were selected as 55°, 60°, 65° and 70°. The RM liner thickness accounts for 0.6 of the total liner thickness, and the RM-liner height accounts for 0.5 of the total liner height. Under different working conditions, the forming characteristics and head velocity of composite jet are shown in Fig. 4. With the increase of the α of the composite liner, the length of the composite jet decreases, but the diameter of the jet increases gradually. The concrete performance is that the composite jet, the slug and the metal titanium core in the jet become thicker with the increase of the α of the RM-liner. This is conducive to maintaining the penetration ability of the jet and having a strong opening ability. However, with the increase of the α of the composite liner, the busbar of the shaped charge liner becomes shorter, resulting in a gradual decrease in the mass of the RMs, which is not conducive to the exertion of the explosive damage power of the RMs.



(a) Formation morphology of jet (b) Jet tip-velocity

Figure 4. Variation of jet head velocity and effective jet length with the cone angle.

At the same forming time, with the increase of the α of the composite liner, the velocity of the formed jet head decreases. This is mainly because, for composite liner shaped charge with the same structure, according to the quasi steady ideal incompressible fluid theory of jet forming, when the α of the shaped charge liner increases, the pressing angle of jet forming increases, eventuating in a decrease in the jet head velocity and an increase in the effective mass of jet. To sum up, when the α of the composite liner is 60°~65°, the head velocity, length, diameter of the formed RM-composite jet and the mass of the RMs are better matched, which is instrumental in the penetration and opening of the RM composite jet to the target, and should be able to produce better explosive damage response.

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4. Conclusions

(1) With the increases of the ratio of reactive material liner thickness, the jet head velocity increases, but the titanium core inside the composite jet is thinner. The composite jet head velocity and RMs quality match well when the ratio is 0.5~0.7.

(2) With the increase of the ratio of RM-liner height, the jet head velocity increases, but the proportion of titanium in jet is little. The composite RM-jet has good comprehensive performance when the ratio is 0.4~0.5.

(3) With the increase of the cone angle of the composite liner, the jet head velocity decreases, but the diameter of the jet increases. The parameters of jet are better matched when the cone angle is 60° ~65° .

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