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Application of Melt-Cast Explosive with High Solid Contents in HEAT Projectile

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Abstract. To improve the power and the safety performance of the HEAT projectile, the charge quality of the melt-cast explosive and the matching relationship between the explosive and the warhead structure were studied. This study breaks through the limitations of the traditional method that based on the ideal composition between solid and liquid phases, and proposes a high-density charging method named "the match relationship between volumes and components". It uses high density spherical RDX as its solid phase and DNAN as liquid phase carrier, with the volume of liquid carrier equal to the packing void of solid phase. Therefore, the internal defect of the charge is reduced, and the explosive energy is increased. Moreover, the structure of warhead of HEAT projectile was optimized according to the characteristics of the melt-cast explosive. In this study, RDX/DNAN instead of the traditional melt-cast explosive (composition B), is used to charge 105mm HEAT Projectile. The results showed that, compared with composition B, the explosive had fewer internal defects and better safety performance, with its density reached 98.3% of the theoretical density; the penetration depth of 105 mm HEAT projectile charged with RDX/DNAN was 11.9% greater than that of composition B; the penetration depth of the optimized HEAT projectile charged with RDX/DNAN was 19.2% greater than that of composition B. It can be concluded that, when the HEAT projectile is charged with the melt-cast explosive, not only the charge density is increased with the charge defect decreased, but also the detonation property is improved.

1. Introduction

Melt-cast explosive has the characteristics of good forming performance, easy loading and low cost, and is commonly used in various types of ammunition such as HEAT projectile, Grenade and High Explosive projectiles. With the increase of the demand of modern warfare on the power performance and safety performance of weapon systems, the traditional melt-cast explosives gradually fail to meet the requirements of high energy and high safety performance of explosive charge, since the problems difficulty in precise control of RDX particle size and shape in traditional melt-cast explosive (composition B) and the large volume shrinkage of TNT phase change lead to low solid content and poor quality of melt-cast explosive. At present, countries around the world are actively exploring methods to enhance the performance of melt-cast explosives. The research methods are roughly classified into three types. The first type use Insensitive Individual Explosives such as NTO, NQ and



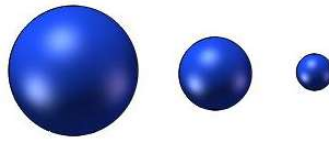
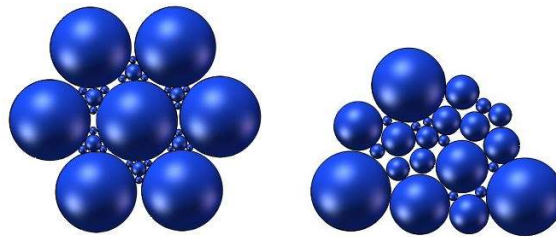
TATB instead of RDX to improve the safety of melt-cast explosives. For example, ARX—4002 melt-cast explosive [1] developed by Australian weapons systems research laboratory has a main composition of 50NTO/50TNT, a detonation velocity of 7370 m/s and a detonation pressure of 22.6GPa. As for AFX-645 melt-cast explosive developed by Alamos laboratory in the United States [2], its main composition is 30TNT/40NTO/10WAX/20AL, with a density of 1.710 g/cm³ and a detonation velocity of 7630 m/s. The second type of research method is to use melt-cast carriers with good safety performance such as DNAN in place of TNT, take the PAX explosives developed by Picatinny Arsenal in the United States[3] for example, which mainly contain 50RDX/30DNAN/20AP, with a density of 1.750 g/cm³ and a detonation velocity of 7395 m/s; As for ARX-4027 melt-cast explosive developed by Australia [4], its main composition is 60RDX/40DNAN, its detonation velocity is 7556 m/s, and its detonation pressure is 21.64GPa .

The third type of research method is to coat RDX and HMX surfaces with paraffin wax, polymer F2311, polyethylene acrylate and other coating agents to improve the safety of explosives. For example, The Central Physical Culture Institute used paraffin wax to coat HMX in non-aqueous medium Novec7200[5]; The Institute of Explosives of Beijing Institute of Technology used demulsification method to coat HMX with polyethylene acrylate [6]; Scholar Smith used solution suspension method to coat RDX and HMX with polyethylene acrylate [7].

The core component of the melt-cast explosive with solid content is the high-density spherical RDX. High density spherical RDX is a RDX crystal with smooth surface, degree of sphericity above 0.9, crystal density of 1.808 g/cm³ and controllable particle size. The high-density of spherical RDX crystal has the density which close to the theoretical density, with fewer defects inside the crystal and good safety performance. Replacing ordinary RDX with highly dense spherical RDX can increase not only the safety of the melt-cast explosives but also the energy level by improving the shape and crystal surface state of RDX and controlling the particle size distribution of RDX. The production of melt-cast explosives started from improving the safety performance and energy level of the explosives, used high density spherical RDX as the solid content, and conducted " high density charge" design for the composition ratio of melt-cast explosive and the particle size distribution of high dense spherical RDX. The method of high-density charge was adopted to prepare explosives with high solid content greater than 80%, charge density greater than 1.720 g/cm³, and detonation velocity greater than 8100 m/s. The melt-cast explosives is superior to composition B in energy level and safety performance. In this paper, melt-cast explosive with high solid content is utilized to replace composition B to fill 105mm HEAT projectile to carry out the application research of melt-cast explosive in HEAT projectile. The research results lay a foundation for the application of melt-cast explosives with high solid content in HEAT projectile.

2. The charge design method of the melt-cast explosive with high solid contents

The traditional theoretical design method of melt-cast explosives is based on the uniform mixing of the solid phases and liquid phases, and the mass ratio of components is determined according to the requirements of energy and oxygen balance. The traditional design method does not consider the matching relationship between the space size and the volume of the components. There will be inevitable internal defects in the design when the volume of the liquid phase carrier cannot fill the solid phase accumulation void volume. Although there is no void inside the theoretical loading, the solid content decreases and the charge density decreases, resulting in a decrease in the energy of the explosive when the volume of the liquid carrier is larger than the volume of the solid accumulation void. On the basis of traditional formula design, The melt-cast explosive use high density spherical RDX as the solid phase and adopts the principle of " the match relationship between volumes and components " to carry out charge design so that the volume of liquid phase carrier is equal to the volume of solid phase RDX accumulation void. The charge design method of the melt-cast explosive is shown in figure 1 to 3.

**Figure 1.** High density spherical RDX

a. Ideal match

b. Improper size matching

Figure 2. Diagram of solid phase particle shape and size matching

a. Liquid phase less

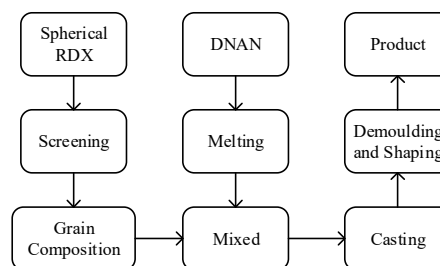
b. Liquid phase excess

c. Ideal match

Figure 3. Volume matching diagram of solid-liquid components

3. The charge experiment of the melt-cast explosive with high solid contents

DNAN is the carrier of the melt-cast explosive, and high density specialized RDX is the solid phases. Figure 4 is the flow chart of the charging process of the melt-cast explosive with high solid contents [8]: Firstly, DNAN was made into a melting pot and heated to melt it completely. Then, highly dense spherical RDX was slowly added and continuously stirred so that the RDX and DNAN are uniformly mixed. At the same time, the projectile body is put into the attemperator for preheating. After a period of time, the mixed molten explosive is injected into the projectile body, and the temperature of the attemperator and the amplitude and frequency of vibration of the projectile body were controlled to solidify the explosive. Finally, the projectile body was removed from the attemperator and cool down, The charge of the projectile is completed when the projectile body temperature is close to room temperature.

**Figure 4.** The flow chart of the charging process of the melt-cast explosive

The experiment used the melt-cast explosive with a mass ratio of 80RDX/20 DNAN. The theoretical density of RDX is 1.816 g/cm^3 , and the theoretical density of DNAN is 1.544 g/cm^3 . The theoretical density of the melt-cast explosive is 1.762 g/cm^3 after theoretical calculation. The theoretical charge density and the density of charge measured by experiment of the 105mm HEAT projectile charged with the melt-cast explosive are shown in Table 1.

Table 1. The theoretical charge density and the density measured by experiment

Projectile number	The theoretical charge density [$\text{g}\cdot\text{cm}^{-3}$]	The density of charge measured by experiment [$\text{g}\cdot\text{cm}^{-3}$]
1	1.762	1.732
2	1.762	1.731
3	1.762	1.733

4. Optimization design of 105mm projectile warhead structure

With the increase of explosive energy, the penetration depth of the HEAT projectile can be increased by designing the cone angle and wall thickness of the liner matched with the melt-cast explosive. According to the literature [9], the lower cone angle of the biconical liner has little influence on the penetration depth compared with the top cone angle. As can be seen from figure 2, the top cone angle ranges from 0 to 48 degrees when the lower cone angle is constant. the cone angle of the biconical liner is no more than 30 degree generally according to the literature [10], so the range of the top cone angle is finally determined to be 30 to 48 degrees and the range of the wall thickness is from 1.0 to 2.4 mm. The numerical simulation techniques was used to get the matching wall thickness and cone angle. The simulated values of the penetration depth of 105mm HEAT projectiles with varying top cone angles and wall thicknesses are shown in table 2.

Table 2. The simulation value of penetration depth of 105 mm HEAT projectile with varying wall thickness and top cone angle

Number	Wall thickness [mm]	top cone angle [°]	The simulation value of penetration depth [mm]
1	1.0	30	511
2	1.0	34	535
3	1.0	38	545
4	1.0	42	523
5	1.0	46	501
6	1.4	30	543
7	1.4	34	565
8	1.4	38	580
9	1.4	42	555
10	1.4	46	520
11	1.8	30	561
12	1.8	34	590
13	1.8	38	610
14	1.8	42	576
15	1.8	46	536
16	2.0	30	576
17	2.0	34	611
18	2.0	38	638
19	2.0	42	591
20	2.0	46	540
21	2.2	30	538
22	2.2	34	568
23	2.2	38	586
24	2.2	42	552
25	2.2	46	520
26	2.4	30	488
27	2.4	34	521
28	2.4	38	542
29	2.4	42	501
30	2.4	46	470

The curved surface of penetration depth under the joint influence of the top cone angle and wall thickness can be obtained by drawing with MATLAB as shown in figure 8. As can be seen from figure 5, the penetration depth achieve the greatest level when the top cone angle is 38° and the wall thickness is 2.0 mm. The warhead structure before and after optimization are shown in figure 6.

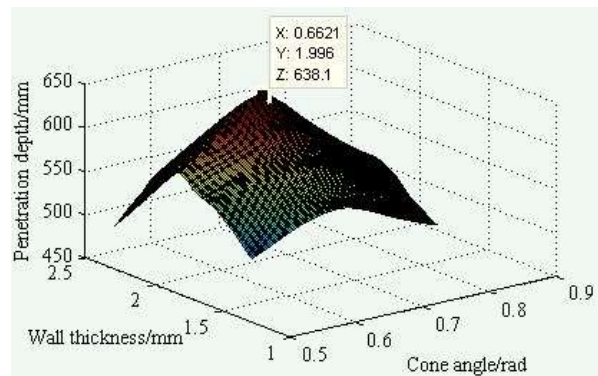
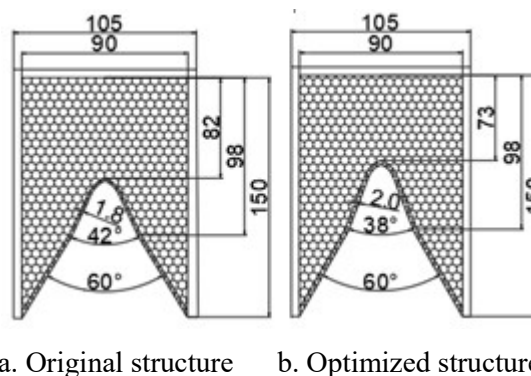


Figure 5. Surface diagram of the penetration depth



a. Original structure b. Optimized structure

Figure 6. Structure of 105 mm HEAT projectile

5. The experiment of 105mm HEAT projectile penetrates the target plate

A total of three projectiles were used in the experiment, the number 2 projectile was optimized, among which the number 1,2 projectiles were charged with melt-cast explosive (RDX/DNAN) and the number 3 projectile was charged with composition B. The size of the experimental device is shown in table 3.

Table 3. Component size of the static steel target experiments of 105mm HEAT projectile

Parts	Warhead	The cylinder for controlling blasting height	Steel target
Size[mm]	$\phi 105 \times 350$	$\phi 95 \times 275$	$\phi 150 \times 650$



Figure 7. The diagram of experimental layout

6. Analysis of experimental results

The experimental penetration depth of the three HEAT projectiles are shown in Table 4. The performance of the melt-cast explosive (RDX/DNAN) and composition B are shown in Table 5.

Table 4. The experimental penetration depth

Projectile number	The experiment value of penetration depth [mm]	A percentage increase in penetration depth compared to projectile 1 [%]
1	520	
2	585	12.5
3	620	19.2

Table 5. The performance of the melt-cast explosive (RDX/DNAN) and composition B

Number.	Project	The melt-cast explosive	Composition B
1	Components	RDX/DNAN	RDX/TNT
2	Density [$\text{g}\cdot\text{cm}^{-3}$]	1.728	1.68
3	Detonation velocity [$\text{m}\cdot\text{s}^{-1}$]	8118	7880
4	Detonation pressure [Gpa]	28.50	26.40

Table 1 shows that the melt-cast explosive reaches 98.3% of the theoretical density. The explosive has charge density which close to the theoretical density, with fewer internal defects and greatly improved safety and energy performance, compared with the Composition B. The reasons are as follows: (1) The design method of high density charge based on spherical RDX makes the arrangement structure of the internal components change from disorder to order, overcoming the defects of the traditional theoretical design method of melt-cast explosives. (2) The common RDX is polycrystalline, with rough crystal surface, irregular shape, low crystal density and poor fluidity, which easily leads to low solid content and poor charge quality of melt-cast explosives. The application of high-density spherical RDX instead of ordinary RDX in the preparation of melt-cast explosives can improve the rheological properties of melt-cast explosives, increase the charge solid content and charge density of melt-cast explosives, and reduce the internal defects of melt-cast explosives, thus effectively improving the energy and safety performance of melt-cast explosives. Replacing ordinary RDX with high-density spherical RDX can improve the rheological properties of melt-cast explosives, increase the charge solid content and charge density, reduce the internal defects, improve the energy and safety performance effectively.

Table 4 shows that the penetration depth of 105mm HEAT Projectile charged with the melt-cast explosive is increased by 12.5% compared with the projectile charged with Composition B; The optimized number 3 Projectile charged with the melt-cast explosive is increased by 19.2% compared with the projectile charged with Composition B. From table 5, it can be seen that the melt-cast explosive (80RDX/ 20DNAN) have high charge density, high volume energy, high detonation velocity and high detonation pressure compared with Composition B.

7. Conclusion

(1) According to the design method of high density charge ,the melt-cast explosive with high solid contents has charge density, which reaches 98.3% of the theoretical density, with few internal defects, higher charge quality and higher safety performance compared with Composition B.

(2) The penetration depth of the 105mm HEAT Projectile filled with the melt-cast explosive is 11.9% higher than that of the HEAT Projectile filled with Composition B. The energy level of the melt-cast explosive with high solid contents is higher.

(3) The penetration depth of the optimized HEAT Projectile filled with the melt-cast explosive is 19.2% higher than that of the HEAT Projectile filled with Composition B. The power of HEAT projectile can be improved by designing the matched structure of warhead.

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