Study on the explosion field temperature and gas products of FOX-7 / RDX based aluminized explosives

X Yang, X Tian, K Zhao, J Dong, Y F Huang, B Feng and X F Wang

Xi’an Modern Chemistry Research Institute, Xi’an 710065, China

E-mail: wangx_f204@163.com

Abstract: To investigate the effect of RDX on the explosion reaction mechanism of FOX-7 based aluminized explosives in vacuum environment, the explosion field temperature of FOX-7 based aluminized explosives and RDX/FOX-7 based aluminized explosives were measured in an isolated explosion chamber. The results show that adding RDX would increase the equilibrium temperature of explosion field of FOX-7-based aluminized explosives. The equilibrium temperature of FOX-7-based aluminized explosives and RDX/FOX-7-based aluminized explosives increases first and then decreases with the increasing of Al content, which shows the highest equilibrium temperature as the Al content is 30%. When the Al content is less than 25%, the explosion peak temperature of FOX-7-based aluminized explosives would increased by adding RDX, and when the aluminium content is more than 30%, the explosion peak temperature of FOX-7-based aluminized explosives can be reduced by adding RDX.

1. Introduction

High energy insensitive mixed explosives have become the mainstream explosives for new series of weapons and ammunition in recent years. Insensitive munitions have been widely studied in the field of ammunition over the world since 1980s, especially for the insensitivity technology of mixed explosives and its performance to the insensitivity of ammunition.

1,1-diamino-2,2-dinitroethylene (FOX-7) is a kind of insensitive explosives with good comprehensive performance, according to the good heat resistance, high energy density and low sensitivity [1-4]. Researchs showed that it would be an insensitive substitute for RDX explosives. Tmicmanis U. et al. [5] studied the thermal decomposition properties of FOX-7. Trzciński W.A. [4] measured the detonation velocity, pressure, heat and metal acceleration of FOX-7, and measured the JWL equation of state parameters of detonation products by cylinder test. The detonation velocity, pressure, energy, heat and energy of FOX-7 explosives and waxed RDX explosives containing Viton A are studied [6]. It is concluded that the detonation pressure, velocity and energy of FOX-7 explosives can be equal to or even higher than waxed RDX. Mishra V.S. et al. [7] used DSC technology to study the thermal decomposition of FOX-7/TNT and RDX/TNT Melt-cast explosives formulations. The results showed that FOX-7/TNT formulations had greater thermal stability than
RDX/TNT formulations. Daniel M.A. et al. [8] comprehensively evaluated the technological properties, energy, slow baking and shock sensitivity of FOX-7. It was found that the slow baking performance and shock sensitivity of FOX-7 were much better than RDX. It was considered that FOX-7 could be used as insensitive booster. However, there are few studies on FOX-7-based aluminized pressed explosives at present, especially the effect of RDX addition on the detonation performance of FOX-7-based aluminized pressed explosives.

The temperature of explosion field is an important performance to evaluate the damage effect of explosives in closed environment. In this study, the effect of RDX on the explosion field temperature of FOX-7-based aluminized pressed explosives in a isolated environment is obtained by using a isolated explosion chamber, and the mechanism of the effect is analyzed and discussed.

2. Experimental Section

2.1. Reagents and Materials

RDX used in this experiment was bought from Gansu Yinguang Chemical Industry Co. Ltd. of China, while FOX-7 was provided by Xi’an Modern Chemistry Research Institute. FLQT4 aluminum powder were provided by Angang Group Aluminum Powder Co. Ltd. The formulations of experimental sample is shown in table 1.

Table 1. The formulations of explosives

| explosives Number | 80 | 15 | 5 | explosives Number | 52 | 28 | 15 | 5 |
|-------------------|----|----|---|-------------------|----|----|----|---|
| XA15              | 75 | 20 | 5 | HXA15             | 48.75 | 26.25 | 20 | 5 |
| XA20              | 70 | 25 | 5 | HXA20             | 45.5 | 24.5 | 25 | 5 |
| XA25              | 65 | 30 | 5 | HXA25             | 42.25 | 22.75 | 30 | 5 |
| XA30              | 60 | 35 | 5 | HXA30             | 39 | 21 | 35 | 5 |

Sample preparation: dissolve the binder in ethyl acetate, put it in water bath and raise the temperature to 60 °C, add explosives and aluminium powder orderly to dissolve the binder, stir evenly, until the solvent volatilize to the paste-like material, sieve, granulate, dry, and finally press into Φ25mm column with 8th detonator hole, the weight of the column is (25.000 ±0. 050) g.

2.2. Experimental facility

The experiment was performed in a self-developed isolated explosives device, as shown in figure 1. The device had a cylindrical body with a height of 400 mm, an inner diameter of 188 mm and a volume of 5.8 L. The temperature sensor was a self-recovering and fast-reacting tungsten-rhodium thermocouple made by the American NANMAC Company. The temperature sensor had a response time of 10⁻⁵ s and was able to withstand a maximum pressure of 135 MPa. The sensor was placed 40 mm away from the center of the top cap, and its boot side was placed 120 mm from the bottom of the end cap. The error of temperature was less than 1%.
Testo 350 gas analyzer can quantitatively analyze the percentage content of O2, NO, NO2, CO and CO2 five gas products. Among them, O2, NO, NO2 and CO are measured using electrochemical sensors with an accuracy of ± 1% and a resolution of 0.01%; CO2 measurement uses an infrared sensor with an accuracy of ± 0.3% and a resolution of 0.01%.

2.3. Experimental Procedure
Suspending the sample in the chamber, where is 20 cm away from the top cap. Then, the detonator was connecting the detonator with the ignition device, and closing the upper cap of the experimental device. evacuating the chamber with a vacuum pump. Filling the explosion device was slowly with nitrogen; repeating the evacuating step to make sure the absolute pressure inside the device less than 100 Pa. Finally, the sample was detonated, and the signal data were recorded within 52 s by the temperature sensors. Then use Testo 350 gas analyzer to collect and quantitatively analyze the explosive gas products.

3. Results and Discussion

3.1. Explosion Field Temperature
The curves of explosion field temperature to time are shown in figure 2 and figure 3. The test time is 52 seconds in total. By the 52nd second, the temperature fluctuation in the chamber is very small, then the equilibrium temperature of explosion field was calculated by the average temperature of 10,000 points in the 52s. The highest point in 0-52s is considered as the peak temperature. The equilibrium temperature of FOX-7-based aluminized explosives is compared with that of RDX/FOX-7-based aluminized explosives as shown in figure 4 and peak temperature as in figure 5.
Figure 2. The explosion field temperature of FOX-7-based aluminized explosives as a function of time.

Figure 3. The explosion field temperature of RDX/FOX-7-based aluminized explosives as a function of time.

Figure 4. Comparison of Equilibrium Temperature between FOX-7-based aluminized explosives and RDX/FOX-7-based aluminized explosives.
Figure 5. Comparison of peak Temperature between FOX-7-based aluminized explosives and RDX/FOX-7-based aluminized explosives.

The equilibrium temperature of the explosion field is an important data reference for assessing the damage performance of explosives in a confined environment. As shown in Figure 4, the equilibrium temperature of FOX-7-based aluminized explosives and RDX/FOX-7-based aluminized explosives increases first and then decreases as the Al content increased from 15% to 35%. The highest equilibrium temperature occurred when the Al content is 30%. While the equilibrium temperature of the RDX/FOX-7-based aluminized explosives is higher than that of the FOX-7-based aluminum-containing explosives, and the difference between the two is obvious when the Al content is 30% and 35%. The trend of the equilibrium temperature as the Al content increased may deeply result from the reaction sensitivity. After the detonation of the drug column, the explosives products of the main explosives and the aluminum powder scatter and collide with each other and react in the explosion tank. When the Al content is less than 30%, the aluminum powder and the main explosives product react more completely in the closed explosion tank. When the aluminum content is 35%, the explosives product of the main explosives is reduced. The reaction was uncompleted, and more aluminum powder remained, resulting in a decrease in heat release and a decrease in equilibrium temperature. The addition of RDX increases the equilibrium temperature of the FOX-7-based aluminized explosives, probably because the RDX detonation product is different from the FOX-7 detonation product and reacting more completely with the aluminum powder.

In Figure 5, the explosion field peak temperature of FOX-7-based aluminized explosives and RDX/FOX-7-based aluminized explosives increased first and then decreased with the increase of aluminum content. The FOX-7-based aluminized explosives achieved the highest at 25% aluminum and the RDX/FOX-7-based aluminized explosives reached the highest at 20% aluminum. When the aluminum content is 15-25%, the peak temperature of the RDX/FOX-7-based aluminized explosives were significantly higher than that of the FOX-7-based aluminized explosives. When the aluminum content is above 30%, the peak temperature of the RDX/FOX-7-based aluminized explosives is significantly lower than that of the FOX-7-based aluminum-containing explosives.

According to the good thermal conductivity and absorbing heat from the detonation products of the hot main explosives, the pure aluminum inside the aluminum powder is melted into a liquid state, and

5
the volume gradually increases, then the surface of the Al_{2}O_{3} shell bursted and the molten aluminum reacts with the oxidizing detonation product. In this experiment, spherical aluminum powder with a particle size of 4μm is used, which is small particle size, large specific surface area and fast thermal conductivity. When the aluminum powder content is low, the energy released by the main explosives detonation instantly makes the aluminum powder rapidly heat evenly and ruptures the alumina outer shell, and the redox reaction releases energy in a very short time, some aluminum powder even burn in the detonation reaction zone [9].

However, when the content of aluminum powder is relatively high, the heat generated by the explosion of the main explosives is not enough to cause all the aluminum powder to reach the combustion threshold, some aluminum powder absorbs the heat and reacts first, releasing heat, and the remaining aluminum powder absorbs heat in the subsequent stage. It does not burn until the reaction threshold is reached. Therefore, with the increase of aluminum powder content, the peak temperature of the explosion field of the two series of aluminum-containing explosives first rises and then decreases. The detonation speed and detonation pressure of RDX are greater than FOX-7, and the addition of RDX leads to an increase in the detonation speed and detonation pressure of the previous main explosives. When the aluminum powder content is high, the aluminum powder in the RDX/FOX-7-based aluminized explosives scatters faster than the FOX-7-based aluminized explosives, so the aluminum powder that quickly reach the reaction threshold temperature is less, so the peak value in the early stage The temperature is also lower.

### 3.2 Analysis of Gas Products

Table 2 showed the measured percentages of O₂, NO, NO₂, CO and CO₂ gas products, and the relative percentage content of remainder oxygen element in the gas is calculated. This method was used in article [10] to calculate the content of remainder oxygen element. the content of remainder oxygen element is 2φ_{CO_2}+φ_{CO}.

| Explosives Number | O₂   | CO₂  | CO   | NO₂ | NO  | Content of remainder oxygen element |
|-------------------|------|------|------|-----|-----|-------------------------------------|
| XA15              | 0    | 2.19 | 39   | 0   | 0   | 43.88                               |
| XA20              | 0    | 4.74 | 36.1 | 0   | 0   | 45.58                               |
| XA25              | 0    | 2.19 | 37.9 | 0   | 0   | 42.28                               |
| XA30              | 0    | 2.58 | 35.2 | 0   | 0   | 40.36                               |
| XA35              | 0    | 1.64 | 30.6 | 0   | 0   | 33.88                               |
| HXA15             | 0    | 2.06 | 38.6 | 0   | 0   | 42.72                               |
| HXA20             | 0    | 4.0  | 34.3 | 0   | 0   | 42.3                                |
| HXA25             | 0    | 2.59 | 36.5 | 0   | 0   | 41.68                               |
| HXA30             | 0    | 0.25 | 35.6 | 0   | 0   | 36.1                                |
| HXA35             | 0    | 0.2  | 31.5 | 0   | 0   | 31.9                                |

From the secondary reaction theory of aluminized explosives, it can be known that the reaction of
aluminized explosives can be divided into three stages: First, the anaerobic detonation stage, mainly the decomposition reaction of elementary explosives in explosives. The second is the anaerobic combustion stage, which is mainly a redox reaction between the aluminum powder and the decomposition products of the main explosive. This reaction does not require external oxygen. The third is the aerobic combustion stage, mainly the flammable components such as aluminum powder remaining in the anaerobic combustion stage react with the oxygen in the surrounding air. The first two stages are the detonation reaction stage of the aluminized explosives, the detonation energy release stage of the explosive itself, and the third stage is the post-combustion stage. Because this experiment is performed in a vacuum environment, there is no third stage reaction. There must be two prerequisites for the oxidation reaction of aluminum powder: one is to be in full contact with the oxidant, and the other is to provide a sufficiently high reaction temperature for the aluminum powder to react with the oxidant. When the detonation product of aluminized explosives expands outward, aluminum powder and oxidizing gaseous products can be brought into close contact by turbulence. Therefore, condition one is not a problem. Therefore, the reaction effect of aluminum powder in aluminized explosives depends on the detonation energy of aluminized explosives release the ambient temperature provided.

Comparing the oxygen element content in the gas after the explosion of XA series and HXA series aluminized explosives, it was found that XA15> HXA15, XA20> HXA20, XA25> HXA25, XA30> HXA30, XA35> HXA35. This is the opposite of the equilibrium temperature of two batches of explosives in an explosion tank, which indicates that the higher the temperature, the more beneficial the aluminum powder and oxidant are to the consumption of oxygen. The heat released by the reaction continues to maintain the high temperature environment and promotes the reaction between the aluminum powder and the oxidant.

4. Conclusion
In the vacuum isolated explosion tank, the variation of the explosion field temperature of FOX-7-based aluminized explosives and RDX/FOX-7-based aluminized explosives were studied, and the following conclusions were obtained:

(1) When the Al content is 15~35%, the equilibrium temperature of FOX-7-based aluminized explosives and RDX/FOX-7-based aluminized explosives increases first and then decreases with the increase of Al content. the highest equilibrium temperature occurred when the Al content is 30%.

(2) The equilibrium temperature of the RDX/FOX-7-based aluminized explosives is higher than that of the FOX-7-based aluminized explosives with a same Al content, and the difference is obvious when the Al content is 30% and 35%.

(3) The peak temperature of the explosion field of FOX-7-based aluminized explosives and RDX/FOX-7-based aluminized explosives increased first and then decreased with the increase of aluminum content. The FOX-7-based aluminized explosives achieved the highest at 25% aluminum and the RDX/FOX-7-based aluminized explosives reached the highest at 20% aluminum.

(4) When the aluminum content is 15-25%, the peak temperature of the RDX/FOX-7-based aluminized explosives is significantly higher than that of the FOX-7-based aluminized explosives. When the aluminum content is above 30%, the peak temperature of the RDX/FOX-7-based aluminized explosives is significantly lower than that of the FOX-7-based aluminized explosives.
References

[1] Bemm U and Ostmark H 1998 ActaCrystallogr C54 1997-8
[2] Karlsson S, Ostmark H and Eldsater C 2002 Int. Symp. Detonation San Diego California
[3] Bellamy A J. 2007 FOX-7 (1, 1-Diamino-2, 2-dinitroethene)//High Energy Density Materials
   Springer Berlin Heidelberg 1-33
[4] Trzcinski W A, Cudziło S, Chyłek Z and Szymańczyk L 2008, Hazard Mater 157 605-12
[5] Ticmanis U, Kaiser M and Pantel G 2004 Int Annu. Conf. ICT Karlsruhe Germany
[6] Trzcinski W A, Cudziło S and Chyłek Z et al. 2013 Journal of Energetic Materials 31(1) 72-85
[7] Mishra V S, Vadali S R and Garg R K et al. 2013 Central European Journal of Energetic
   Materials 10
[8] Daniel M A, Davies P J and Lochert I J 2010 FOX-7 for insensitive boosters Defence
   Scienceand Technologyor Ganisation Edinburgh (AUSTRALIA) Weapons Systems DIV
[9] Anderson P, Balas W and Nicolich S et al. 2009 Proceedings Insensitive Munitions & Energetic
   Materials Technology Symposium, Tucson: NDIA 11-4
[10] Huang Y F, Tian X and Feng B et al. 2016 Chinese Journal of Energetic Materials 24(124) (02)
    44-8