Constant-volume combustion performance of mixed charge of foamed propellant with nitramine propellant

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Abstract. Foamed propellants based on polymer bonded nitramine explosives show high burning rates due to their porous structure and showed great potential for combustible cartridge case. Thus, the in-depth study of the co-combustion behavior of the foamed propellant and matching propellant is necessary. In this paper, closed bomb tests were used to study the co-combustion performance of nitramine propellant (RGD7) and surface coated nitramine propellant (SC-RGD7) mixed with foamed propellant. The influence of foamed propellant’s proportion in mixed charges on the combustion behavior was studied and analysed. It was found that the maximum dynamic vivacity and the value of B at maximum dynamic vivacity of mixed charge increased with the increase of added foamed propellant, resulting in better combustion progressivity. Meanwhile, the ignition delay of foamed propellant influenced the first stage of combustion, and the penetration combustion of foamed propellant influence the middle stage.

1. Introduction

The foamed propellants based on polymer bonded nitramines have several superiorities like variable energy content, high burning rate, good heat resistance and low vulnerability [1, 2]. Nowadays, the energy content of foamed propellants is variable from 900 J/g to 1300 J/g [3-5]. Among these foamed propellants, the high energy foamed propellants are suitable for caseless ammunition or monolithic charge, and the lower energy propellants are desired to be the alternate for traditional combustible cases which were very inflammable and hypergolic in gun chamber [6, 7]. However, when the foamed propellant is loaded in a combustible cartridge, the combustion behavior of the mixed charge composed of matching propellant and foamed propellant in the gun chamber is quite different, and the combustion parameters are not a simple addition of the two in proportion.

The improvement of performance of ballistic components depends on the understanding of the combustion behavior taking place during the ballistic cycle. While, the presence of combustible case complicates the burning process, in that it differs in its combustion characteristics from the traditional propellant, and the combustible case is a porous materials. The burning characteristics of these porous materials showed specialties compared to standard gun propellants and it was usually considered that the burning behavior of foamed propellants deviates from Vieille’s law and the combustible material was simply converted to a certain mass of main charge according the value of force content [8, 9]. For the complexity of the co-combustion behavior, current predictions of interior ballistic simulations fail when based on a straightforward use of it. Thus, a complete description of the combustion mechanism
of this new type of combustible material, including any effects produced by test and charging conditions, is necessary for the further application.

Stated thus, the underlying purpose of this study is the characterization of the co-combustion behaviors of foamed propellant with matching propellant by experiment. The co-combustion characteristics of polyurethane/RDX-based propellants with matching nitramine propellants were investigated. The results of this study will apply primarily to further development of the mixed charges. The findings may also be applicable to other applications which take advantage of foamed propellant as combustible objectives or something like combustion modifier.

2. Experimental Section

2.1. Foamed propellant and matching nitramine propellant

Foamed propellants (FP) were prepared by mixing polyol, Toluene diisocynate (TDI, 80/20 isomer ratio), RDX and other components (surfactant, catalysts and water as blowing agent). The continuous phase is polyurethane foamed and the dispersion phase is RDX which mass fraction is 70%. The force content and 5 s explosion temperature of the foamed propellant is 900 J/g and 305°C, respectively. More details about the fabrication process of foamed propellant were discussed in [10].

RGD7 nitramine propellant is a type of high energy gun propellant widely used in high-pressure gun. Here, RGD7 nitramine propellant with 7-perforated geometry and surface coated RGD7 nitramine propellant (SC-RGD7) were used as matching propellants. More details about RGD7 and SC-RGD7 were reported in [11-13].

Table 1 presents the properties and formulations of foamed propellant and nitramine propellant.

| Propellant | Force content (J/g) | 5 s explosion temperature/°C | Formulation |
|------------|---------------------|-----------------------------|-------------|
| FP         | 900                 | 305                         | 70%RDX, 30%Polyurethane foam[^10] |
| RGD7       | 1226                | 265                         | 30.0%NC(12.6N%), 25.2%NG, 26.6%RDX, 15.4%NQ, 2.8% additives[^11-13] |

2.2. Closed bomb tests

The combustion properties were investigated by closed vessel test. The volume of closed vessel is 109 mL and the data sampling interval was 0.001 ms. Foamed propellants were tested with loading density
of 0.12 and 0.20 g/cm³. Mixed charges were tested with loading density of 0.20 g/cm³. The ignition pressure of closed bomb test was 10.98 MPa and initial temperature of 20°C. The ignition powder is 2# nitrocellulose with 12.6N%. Different schemes of closed-bomb tests are listed in Table 2.

Table 2. Different schemes of closed-bomb tests.

| No | propellants | mixed mass ratio |
|----|-------------|------------------|
| 0  | FP          | -                |
| 1  | RGD7        | -                |
| 2  | SC-RGD7     | -                |
| 3  | FP/RGD7     | 3:1              |
| 4  | FP/RGD7     | 1:1              |
| 5  | FP/RGD7     | 1:3              |
| 6  | FP/SC-RGD7  | 3:1              |
| 7  | FP/SC-RGD7  | 1:1              |
| 8  | FP/SC-RGD7  | 1:3              |

3. Results and discussions

3.1. The burning behaviors of foamed propellants

The foamed propellants were tested at two loading densities of 0.12 and 0.2 g/cm³ to reveal the relationship between loading density and burning behaviors. The p-t, dp/dt-t and dynamic vivacity (L-B) curves of foamed propellant are presented in Figure 2. As figure 2(a) indicated, as the loading density increased, the maximum pressure increased from 116 MPa to 188 MPa and the total burning time (including combustion of ignition powder, ignition delay and combustion of foamed propellant) decreased from 23 ms to 18 ms.

Since the foamed propellant was hard to get ignited and penetrated by ignition gases contributed by the heat-resistant formulation and closed pore structure, the pressure history of foamed propellant contained an initial pressure rise of ignition powder combustion (Peak 1) and the pressure rise of combustible case (Peak 2 and 2'). According to the ignition theory, the ignition delay is not influenced by loading density. Thus, the overlap section in p-t curves or dp/dt-t curves between Peak 1 and 2 (or 2') could be judged as the ignition delay period, after which the pressure diverged from each other for different loading densities. As a result, the ignition delay time was about 5 ms. While for felted combustible cartridges and propellants grains, there was no clear-cut distinction of these two combustion period [14].

By the same token, the initial dynamic vivacity value was almost zero due to the ignition delay. In the meantime, the maximum dynamic vivacity at different loading density was obtained at the almost same B value, which means the combustion mode is similar.

![Figure 2](image-url)

Figure 2. p-t (a), p/dt-t (b), and L-B (c) curves for foamed samples at different loading densities.
3.2. The influence of foamed propellant on combustion of nitramine propellant
In order to study the effect of foamed propellant on the combustion performance of 7-perf nitramine propellant (RGD7), different ratios of foamed propellant were mixed to nitramine propellant and tested. The p-t and L-B curves of RGD7 and SC-RGD7 with different ratios of foamed propellants are presented in figure 3 and 4, respectively. As shown in figure 3 and 4, with the increase of foamed propellant, the burning time increased. Meanwhile, the maximum pressure decreased resulting from the lower energy content of foamed propellant. It can also be seen that the value of B at maximum dynamic vivacity increased with the increase of ratio of foamed propellants (revealed from the dotted line marked in figure 3 and 4). What’s more, the initial dynamic vivacity value decreased with the increase of foamed propellant.

![Figure 3](image1.png)
**Figure 3.** p-t (a) and L-B (b) curves of RGD7 mixed with different ratios of foamed propellants.

![Figure 4](image2.png)
**Figure 4.** p-t (a) and L-B (b) curves of SC-RGD7 mixed with different ratios of foamed propellants.

3.3. The influence of surface coating of nitramine propellant on the combustion behavior
In order to study the effect of the surface coating of nitramine propellant on the combustion performance of the mixed propellant, figure 5 and 6 compares the p-t and L-B curves of coated and uncoated nitramine propellants with various ratios of foamed propellants. As shown in figure 5, the pressure rises more slowly at the early stage for surface coated propellant, and thus resulting in increased burning time. Simultaneously, the same trends are also mirrored for mixed charges with foamed propellant. As figure 4 indicated, the curve after maximum dynamic vivacity has a good coincidence with each other, revealing that the surface coating only influenced the ignition and initial burning period of mixed propellants.
3.4. Interaction mechanism of mixed charge

In order to study how foamed propellant influenced the combustion of nitramine propellants, \( L-B \) curves of mixed charges compared with nitramine propellants were listed and compared in figure 7. It can be seen that there are two intersections a and b in the \( L-B \) curves of the mixed charge and the nitramine propellant. Thus, the \( L-B \) curves were divided into three regions artificially to study the period during which foamed propellants participated in the combustion of mixed charges.

It is considered to be the burning of nitramine propellant before point a, resulting from the lower dynamic vivacity of foamed propellant under lower pressure. Between point a and b, it is the co-combustion period of the nitramine propellant with foamed propellant, and the dynamic vivacity value during this period was higher than that of RGD7 or SC-RGD7. As the ratio of foamed propellant increased, the co-combustion period extended for both RGD7 and SC-RGD7 propellant. After the point b, the dynamic vivacity value of mixed charge is lower than that of propellant, resulting from lower RGD7 propellant mass at a loading density of 0.20 g/cm\(^3\). What’s more, when the ratio of foamed propellant is lower, the coincidence of two \( L-B \) curves is better, indicating weakened influence of foamed propellant.

As a contrast, the combustion behavior is quite different from that of mixed charge composed of gun propellant grains and felted combustible cartridge case (62% NC, 24.5% paper fiber, 13.5% binder and additives). For the felted combustible cartridge case, there was only one intersection on \( p-t \) curves of gun propellant and mixed charge, and felted combustible cartridge case burned out before the first intersection point for the inflammability [15].
4. Conclusions

Foamed propellants presented a significant difference in inner structure and burning characteristics, in comparison with the traditional 7-perf nitramine propellant and felted combustible cartridge case. Compared with felted cartridge case, foamed propellants also presented good burning progressivity and heat resistance, revealing great potential for application of combustible cartridge case.

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