Research on the Combustion Performance of Mixed Charge of the Super-porous Coated Propellant

Cao Xiang1*, Zhang Lina1, Du Ping1, Jiang Shuai1, and Nan Fengqiang1
1Nanjing University of Science and Technology, Nanjing 210094, China
*1614911232@qq.com

Abstract. In order to study the constant volume combustion performance of the mixed charge of super-porous propellant and super-porous coated propellant, 37-hole nitroguanidine propellant and 37-hole nitroguanidine coated propellant containing flame retardant TiO2 were prepared. At high temperature(50℃), normal temperature(20℃), low temperature(-40℃), a constant volume combustion experiment was performed on a mixed charge with a mass ratio of 1: 1 for the 37-hole propellant and the 37-hole coated propellant. The research results show that the constant volume combustion performance of the mixed charge is different from a single coated propellant and a single base propellant. The p-t, dp/dt-t and L-B curves of the mixed charge were between the coated propellant and the base propellant, but mixed charge has the greatest progressive combustion. And the temperature dependence of the progressive combustion of mixed charge is small, which has a certain low temperature effect.

1. Introduction
With the development of charging technology, the use of porous propellant combined with flame retardant coating and other processing methods can further improve the progressive combustion of the propellant[1]. Adopting a mixed charge structure (that is, the base propellant and the coated propellant are used together) can improve the progressive combustion of the propellant and effectively increase the charge density of the propellant, and can also improve its ignition consistency and muzzle velocity[2-3]. A mixed charge containing a certain proportion of coated propellant can change the combustion law in the firing chamber, compensate for the effect of the change in burning rate caused by temperature changes, increase the pressure platform effect of the p-t curve, improve the efficiency of the gun and reduce the temperature coefficient of the charge trajectory[4]. Xue et al.[5] studied the combustion performance of mixed charge of deterred oblate spherical propellant, and the results showed that the combustion property was better when the deterred oblate spherical propellant was mixed with main charge propellant. Xu et al.[6] studied the constant volume combustion performance of the mixed charge of slotted stick propellant and deterrent coated propellant, and analyzed the combustion mechanism interaction of slotted stick propellant and deterrent coated propellant. The results indicated that the slotted stick propellants and deterrent coated propellants interact seriously in the early stages of combustion, however, as the combustion progresses, the interaction between them gradually weakens. Researchers have conducted more research on the mixed charge of propellant, but there is no report on the combustion performance of the mixed charge of 37-hole propellant and 37-hole coated propellant.

The research group conducted in-depth research on the 37-hole coated propellant. Zhang et al.[7] used a double-layer coating process to coat the 37-hole nitroguanidine propellant. A coated propellant with a uniform thickness and a good compatibility between the coating layer and the base propellant...
was obtained and its constant volume combustion performance was studied. The results showed that
the coated propellant has a better progressive combustion. Based on this, 37-hole base propellant and
37-hole coated propellant are mixed with a charge ratio of 1: 1, and the mixed charge system is
subjected to constant volume combustion experiments under high temperature, normal temperature
and low temperature conditions. The p-t, dp/dt-t, L-B curves are obtained by data processing. With
this, the combustion performance of the 37-hole coated propellant mixed charge is analyzed and
studied.

2. Experimental

2.1. Experimental Materials
37-hole nitroguanidine propellant, Liaoning Qingyang Special Chemical Co., Ltd; Triguanine-15
absorption tablets, Liaoning Qingyang Special Chemical Co., Ltd; Nitroguanidine, Liaoning Qingyang
Special Chemical Co., Ltd; TiO₂, 99.8% 100nm anatase, Shanghai Aladdin Biochemical Technology
Co., Ltd; acetone, ethanol, AR, Nanjing Chemical Reagent Co., Ltd.

2.2. The Main Equipment Used in the Experiment
Electronic balance, 1000g (0.001g), Shanghai Jingke Tianmei Trading Co., Ltd; digital display
constant number mixer, JB-90D, Hunan Lichen Technology Co., Ltd; drum coating machine, Taizhou
Liming Pharmaceutical Machinery Co., Ltd; steam generator, LDRO.017-O, Zhangjiagang Fucheng
Thermal Energy Equipment Co., Ltd, water bath oven, AHX safety type, Nanjing University of
Science and Technology; multifunctional Machine Tool, H11-1, Shanghai Eleventh Machine Tool
Factory; rotary Viscometer, NDJ-1, Shanghai Jinghai Instrument Co., Ltd.

2.3. Preparation of Coated Propellant
First, the inner and outer coating liquid (solid flame retardant is TiO₂) were prepared, then the
prepared 37-hole propellant was putted into the drum coating machine to begin coating. After the inner
coating process was finished, the sample was air-dried at room temperature for 1 day, and then the
outer coating process was performed. After that, the outer-covered sample was also air-dried at room
temperature for 1 day, and finally the prepared sample was placed in a water bath oven at 50℃ for 7
days to remove the residual solvents, then the sample was sealed and kept.

2.4. Confined Explosive Device Experiment
In order to reduce the complexity of the experiment and understand the progressive combustion of the
coated propellant under the same formula, we first selected a single-hole tubular base propellant with
the same formula as the 37-hole propellant as the research object, and made a single-hole tubular
coated propellant by the semi-solvent method. Under the conditions of packing density of 0.2g·cm⁻³
and normal temperature and pressure, a constant volume combustion experiment was performed, and
the p-t and u-p curves were obtained through data processing to analyze the progressive combustion of
the coated propellant.

Based on this coating, this article further discusses the progressive combustion of the 37-hole
coated propellant mixed charge. 37-hole base propellant and 37-hole coated propellant were mixed in
a charge ratio of 1: 1, and constant volume combustion experiments were performed under high
temperature (50℃), normal temperature (20℃), and low temperature (-40℃) conditions. The volume
of the closed explosive device was 107.39cm³, the packing density was 0.33g·cm⁻³, the ignition
powder was No. 2 nitrocellulose, the dose was 1 ± 0.0005g, the ignition pressure was 10.39MPa, and
p-t, dp/dt-t, L-B curve were obtained through data processing.

3. Results and Discussion

3.1. Performance of Coated Propellant and Base Propellant
Figure 1 is the p-t and u-p curves of a single-hole coated propellant and a single-hole base propellant at normal temperature and pressure. It can be seen that the coated propellant with the flame retardant TiO$_2$ and the base propellant are two completely different combustion behaviors.

From Figure 1 (a), it can be seen that the base propellant burns quickly and reaches the maximum pressure quickly, and the pressure increases exponentially throughout the combustion process. While the coated propellant has a slow pressure increase in the initial stage of combustion and the pressure growth rate is slowly increasing. At the same time, the pressure value $p$ (base propellant)$> p$ (coated propellant), the pressure of the base propellant is much greater than the pressure of the coated propellant, and because the coating layer contains flame retardant substances, it affects the total energy of the propellant and reduces the maximum pressure. The burning end time $t_m$ (base propellant) < $t_m$ (coated propellant), the time to reach the maximum pressure, the coated propellant $t_m$ is about three times the base propellant $t_m$; It can be seen from Figure 1 (b) that the u-p curve of the coated propellant is below the base propellant. When the pressure is the same, the burning rate of the coated propellant is lower than that of the base propellant.

![Figure 1. p-t and u-p curves of coated propellant and base propellant at normal temperature and pressure](image)

The above shows that TiO$_2$ as a non-energetic substance reduces the energy of gunpowder in the propellant, so its pressure rises slowly, the burning speed is slower, and the flame retardance of the coating is better.

The burning rate pressure index $n$ is an important parameter to characterize the burning performance of gunpowder, and its size reflects the sensitivity of the propellant burning rate to pressure changes. It can be known from Table 1 that the burning rate pressure index in different pressure sections is less than 1, and in conjunction with Figure 1 (b), it can be seen that the burning rate growth rate in the high pressure section increases with the increase in pressure. From the entire pressure range (50-Pdmp) MPa, it can be concluded that the burning rate coefficient $u_1$ (base propellant)$> u_1$ (coated propellant), and the burning rate pressure index $n_1$ (coated propellant)$> n_1$ (base propellant).

| Sample            | $p_m$/MPa | $t_m$/ms | Parameter | $p_{50-100}$/MPa | $p_{50-Pdmp}$/MPa | $p_{Pdmp}$/MPa |
|-------------------|-----------|----------|-----------|------------------|------------------|----------------|
| Coated propellant | 145.06    | 27.90    | $u_1$     | 0.1048           | 0.0893           | 132.24         |
|                   |           |          | $n_1$     | 0.8582           | 0.8964           |                |
| Base propellant   | 165.36    | 14.24    | $u_1$     | 0.1585           | 0.1251           | 241.95         |
|                   |           |          | $n_1$     | 0.8547           | 0.9040           |                |

Table 1. Combustion performance parameters of base propellant and coated propellant
### 3.2. 37 Constant Volume Combustion Performance of Porous Propellant Mixed Charge

#### 3.2.1. p-t curve of mixed charge of ultraporous coated propellant

Figure 2 is the p-t curve of 25/37 base propellant, 25/37 double-layer coated propellant, and 1:1 ratio of base propellant and coated propellant mixed charge. It can be seen from Figure 2 that under low temperature (-40℃), normal temperature (20℃), and high temperature (50℃) conditions, the p-t combustion curve of the mixed charge is between the double-layer coated propellant and the base propellant. It is because the base propellant and the double-layer coated propellant in the mixed charge affect each other during constant volume combustion. In the initial stage of combustion, the double-layer coated propellant burns slowly due to the coating effect on the surface, and the burning of the base propellant has a greater surface enhancement. Under the dual effects of the base propellant and the coated propellant, pressure increase of mixed charge is smaller than the base propellant but larger than the double-layer coated propellant; at the same time, because the base propellant participates in the combustion at the beginning of the combustion, the pressure increases rapidly, and the time for the hole breaking of the double-layer coated propellant is earlier, making the combustion law of the mixed charge different from that of the single coated charge, that is, the burnout time of the propellant is relatively short.

![Figure 2. p-t curve of 37 porous coated propellant mixed charge](image)
Figure 3. p-t curve of 37 porous coated propellant mixed charge

As can be seen from Figure 3, when the temperature is higher, the tm is smaller. In the coated charge, the p-t curve under the low temperature condition moves farther backward, while in the mixed charge, the p-t curve under the three temperature states is closer, which indicates that the coated propellant changes the combustion law of the propellant more significantly under low temperature conditions, and also verifies that the mixed charge has a certain low temperature effect.

3.2.2. dp/dt-t curve of mixed charge of ultraporous coated propellant
Figure 4. dp/dt-t curve of 37 porous coated propellant mixed charge

It can be seen from Figure 4 that the growth rate of the pressure of the mixed charge in a constant volume is higher than that of the coated propellant and lower than that of the base propellant. The time for the pressure growth rate of the base propellant, mixed charge, and coated propellant to reach the maximum value increases in turn. This is the result of the mutual influence of the base propellant and the coated propellant during combustion. The specific reasons have been previously analyzed and will not be discussed here.

It can be seen from figure 5 that the higher the temperature, the larger \((dp/dt-t)_{m}\). It can be seen from Figure 5 (a) that the sharp decline of the burning surface after the propellant splits is more evenly distributed at high temperature, normal temperature and low temperature; from Figure 5 (b), it can be seen that the time of the sharp decline of the burning surface after the propellant is split under low temperature conditions after the coating is propelled backward, which indicates that the coated propellant changes the burning rule of the propellant at low temperature conditions more significantly; from Figure 5 (c) it can be seen that the constant volume combustion of the mixed charge changes the combustion law of the propellant. The time of the propellant split point at low temperature is earlier than the time at normal temperature, which also shows that the mixed charge has a certain effect of low temperature.
3.2.3. L-B curve of mixed charge of ultraporous coated propellant

It can be seen from figure 6 that the base propellant has a visible erosion combustion peak at the initial stage of combustion, and the dynamic activity of the mixed charge with the coated propellant was suppressed in the early stage. The L-B curves of the mixed charge and the coated propellant are similar. The L value of the mixed charge is greater than the coated charge in the rising phase and smaller than that in the falling phase. From the difference of $\Delta L$ at different temperatures, the difference of the mixed charge at different temperatures is smaller than the base drug and the coating, that is, the increasing dependence of the mixed charge on the temperature is small, which is the unique effect of the mixed charge structure.

4. Conclusion
(1) TiO$_2$ is added to the coating liquid as a non-energetic substance, which reduces the energy of the gunpowder in the propellant. Compared with the base propellant, its pressure rises slowly, the burning speed is slow, and the flame retardant effect of the coating is good.

(2) The constant volume combustion of the mixed charge changed the combustion law of the propellant. The p-t, dp/dt-t and L-B curves of the mixed charge are between the coated propellant and the base propellant, but mixed charge has the greatest progressive combustion. And the temperature dependence of the progressive combustion of mixed charge is small, which shows that mixed charge has a certain low temperature effect.

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