Study on Infrared Radiation Characteristics of Granular Mg/PTFE/NC Agent

Lei Wang*a, Jian Ju*b and Hua Guan*

School of Chemical Engineering, Nanjing University of Science and Technology, Nanjing, China

*Corresponding author e-mail: guanhua@njust.edu.cn, *wanglei7374@yeah.net, b1693326328@qq.com

Abstract. In order to improve the radiation radiation area of Mg-PTFE infrared bait agent and reduce the radiation intensity, the Mg/PTFE/NC particle type agent was prepared by solvent evaporation method to study the infrared radiation performance of the particle agent. The results showed that the radiation area of the granular agent increased by 60% on average and the radiation intensity decreased by 84% compared with the equal-quality powdery agent. For granules, the radiation performance increases with the increase of particle size. When the particle size increases from 690.6 μm to 1048.3 μm, the average radiation area increases from 139.51 cm² to 172.83 cm², and the average radiation intensity is 2.89 W·Sr⁻¹ increased to 4.56 W·Sr⁻¹; while the mass fraction of Mg-PTFE in the granules also increased with the increase of mass fraction, and the effect on the radiation area was small; mass fraction When increasing from 30% to 70%, the radiation intensity increases from 2.64 W·Sr⁻¹ to 5.62 W·Sr⁻¹.

1. Introduction

The typical MTV infrared bait based on Mg-PTFE (magnesium-polytetrafluoroethylene) has been the infrared-guided weapon nemesis for its high infrared radiation performance, and its infrared radiation is mainly burned by the powdered bait agent pressed into the charge of the drug column. Compared with the protected target, the main features are high radiation temperature, high radiation intensity, and small radiation area. At present, the infrared guidance method has been developed from point source to imaging guidance, and its anti-interference technology has been greatly improved. The significant difference between infrared decoy and target radiation performance can be distinguished by the infrared imaging guidance of the bait and target [1, 2]. Therefore, the Mg-PTFE is made into particles, in an attempt to increase the radiation area of the agent, and to appropriately reduce the radiation intensity.

Traditional methods for preparing particles in propellants include endolysis and exolysis [3-5]. The internal solution method is to mix and dissolve the material, the solvent and the water in the reactor, and after the dissolution is completed, the protective gel is added to cover the dispersed droplets, and after heating and dissolving, the microporous particles are obtained. The external dissolution method is that the material containing nitrocellulose is prepared into a more viscous sol for direct extrusion granulation, and then the granule preparation is carried out by means of additional mechanical granulation. In recent years, many other methods have appeared in the preparation of energetic material particles. For example, Wang Jiang et al [6] successfully prepared spherical RDX particles by spray drying method; Liu
Huanmin [7] successfully prepared by microfluidic technology. Single-base and double-base spherical propellant particles were produced; Shi Xudong et al. [8] prepared polyactic acid microporous particles by solvent evaporation method, and the particle shape uniformity was good, but the experimental dissolving process lasted for 4 hours, and the efficiency was low; Ping [9] and other methods used leaching method to prepare nitrocellulose microporous particles by aqueous solution leaching at room temperature. This method greatly reduced the preparation time, but the obtained granules were soft.

Based on the above preparation method, it is proposed to prepare the pyrotechnic agent Mg/PTFE/NC particles by the solvent volatilization method, and to coat the Mg and PTFE into spherical or nearly spherical particles by using the excellent adhesion of the NC. The effects of different ratios of particles and different particle sizes on the radiation area and radiation intensity of particles after combustion were studied.

2. Experiments

2.1. Preparation of Mg/PTFE/NC particles
Take the preparation of nitrocellulose with a mass fraction of 50% as an example: weigh a certain amount of nitrocellulose, magnesium powder, and polytetrafluoroethylene in a three-necked flask, add a certain amount of ethyl acetate, and stir at 64 degrees to form a thick. After the polymer sol was added, an emulsifier and a dispersing agent were added, and the temperature was raised while stirring was accelerated until the solvent ethyl acetate was completely distilled off, and then allowed to stand, suction-filtered, and dried to obtain Mg/PTFE/NC particles.

2.2. Test sample pretreatment
For the particles with different mass ratio of raw materials, the particles with a particle size of 600-800 μm were sieved, 2 g of the sample was weighed, the column was pressed with an external force of 5 kN, and a cylindrical shell with a height of 33 mm and an inner diameter of 20 mm was placed to prepare a sample. 1 - Sample 5. For the particles with the same mass ratio of raw materials, the particle size distribution of different particles was measured by a laser particle size analyzer, and 2 g of the sample was weighed separately, and the column was pressed with a force of 5 kN to be loaded into a casing of the same size to prepare a sample 6 to a sample 9. Separately, 2 g of a powdery Mg-PTFE agent was prepared, pressed with the same external force, and placed in a casing, which was used as a comparative sample No. 0. The figure below shows the processed sample.

![Sample schematic.](image)

2.3. Particle size test
In this paper, the particle is tested by the British Malvern Mastersizer 2000 dry laser particle size analyzer. The particle size range of the instrument is 0.02μm~10000μm. After analysis, the particle size and particle size distribution of the sample can be obtained. The particle size distribution of Sample 6 to Sample 9 obtained by the test is shown in Figure 2 below.
2.4. Infrared test instrument and test method

Test instrument: American Flir SC7000 far-infrared thermal imager, spectral response band 7.7~9.3μm; resolution 320×240 pixels; temperature resolution <20mK; test lens 25mm, background, atmospheric temperature 20℃, room temperature 25℃, emissivity Set to 1.

Test method: During the test, the test sample is placed on the test bench in front of the instrument lens, and it is determined that the sample is filled in the field of view, and the measured distance is 3.4 meters. The burning surface of the sample is facing the instrument. After igniting the surface ignition powder, the sample burns rapidly and the sample is burned. Sample burning time, radiant temperature, and radiation were obtained using a far infrared camera.

Radiation area calculation: Select an object of known length and measure the number of pixels it occupies in the camera to establish a scale to calculate the radiation area of the sample at different times. Calculation of radiation intensity: according to formula (1):

\[
I = LΔA \cos \theta
\]

Where \( I \) is the radiation intensity, W•Sr\(^{-1}\); \( L \) is the radiance, W•Sr\(^{-1}\)•m\(^{-2}\); \( A \) is the radiation area, m\(^2\); \( \theta \) is the normal angle from the non-point source, set in the test 0. The radiance \( L \) is calculated by the thermal imager's own software ResearchIR. The calculation method of the radiation area \( A \) is as above, and the radiant intensity \( I \) of the sample is calculated according to the formula (1).

3. Results and discussion

3.1. Study on Radiation Properties of Different Ratio Mg/PTFE/NC Particles

Due to the different ratios of the medicaments, there is a direct influence on the particle size of the particles. Firstly, the effects of different proportioning agents on the radiation performance are studied. Table 1 shows the raw material ratio and particle size of different proportions of samples. The mass fraction of nitrocellulose in samples 1~5 increased in turn, and the mass fraction of magnesium powder and polytetrafluoroethylene decreased in turn. The results of thermal imaging at different times after combustion of different proportioning agents were tested by infrared camera. No. 0 is a powdery medicament.

| sample | NC / % | Mg / % | PTFE / % |
|--------|--------|--------|---------|
| 0      | 0      | 50     | 50      |
| 1      | 30     | 35     | 35      |
| 2      | 40     | 30     | 30      |
| 3      | 50     | 25     | 25      |
| 4      | 60     | 20     | 20      |
| 5      | 70     | 15     | 15      |

*Figure 2. Schematic diagram of particle size distribution of sample 6 - sample 9*
It can be seen from Fig.3 that the radiation area of the No.1 to No.5 sample is significantly larger than that of the No.0 sample, and the duration is also longer. The difference in radiation area between samples 1 and 5 is small, and the overall duration of the increase is increasing. From the temperature table on the left, it can be seen that the overall radiant temperature gradually decreases from the No.1 sample to the No.5 sample, and both are lower than the No.0 sample. The following is a numerical calculation to illustrate the effect of the ratio of Mg/PTFE/NC sample on the radiation area and radiation intensity.

3.1.1. Effect of Mg/PTFE/NC sample ratio on radiation area. The average radiation area under combustion of each sample was calculated by thermal imaging software as shown in Table 2.

| Sample | Maximum radiation area $S / \text{cm}^2$ | Average radiation area $S / \text{cm}^2$ | Increase ratio / % |
|--------|----------------------------------------|----------------------------------------|-------------------|
| 0      | 107.78                                 | 97.61                                  | /                 |
| 1      | 136.48                                 | 121.36                                 | 24.3              |
| 2      | 143.84                                 | 126.88                                 | 29.9              |
| 3      | 148.21                                 | 124.04                                 | 27.1              |
| 4      | 137.92                                 | 131.89                                 | 35.1              |
| 5      | 150.88                                 | 118.72                                 | 21.6              |

It can be seen from the table that when the mass percentage of nitrocellulose is 30%, 40%, 50%, 60%, 70%, the average radiation area of the particles is 121.36, 126.88, 124.04, 131.89, 118.72 cm$^2$, respectively, and the radiation area between them is different. Not large, this shows that the ratio of raw materials is not the main factor affecting the size of the radiation area. Compared with the powdered Mg-PTFE agent, the radiation area increased by 24.3%, 29.9%, 27.1%, 35.1%, 21.6%, respectively, and the average increase rate was 27.6%. This indicates that the preparation of Mg/PTFE/NC particles can increase the radiation area of the agent.

3.1.2. Effect of Mg/PTFE/NC sample ratio on radiation intensity. The radiation area calculated above is multiplied by the radiance calculated by the software ResearchIR, that is, the variation of the radiation...
intensity of the different ratio samples and the sample No.0 is as shown in FIG.4 Table 3 shows the average radiation intensity at the time of burning each sample.

**Figure 4.** Radiation intensity change diagram of different proportioning samples and sample No.0

| sample | radiation duration $t$ / s | average radiation intensity $I$ / W•sr^{-1} | increase ratio / % |
|--------|---------------------------|---------------------------------------------|-------------------|
| 0      | 3.4                       | 18.60                                       | -                  |
| 1      | 5.2                       | 5.62                                        | -69.8             |
| 2      | 5.4                       | 4.15                                        | -77.7             |
| 3      | 5.2                       | 3.45                                        | -81.5             |
| 4      | 4.2                       | 3.16                                        | -83.0             |
| 5      | 5.5                       | 2.64                                        | -85.8             |

Referring to Fig.4 and Table 3, the average radiant intensity of Mg/PTFE/NC particles burning at different ratios is 5.62, 4.15, 3.45, 3.16, 2.64 W•sr^{-1}, respectively, which is 69.8% lower than that of powdered Mg-PTFE. 77.7%, 81.5%, 83.0% and 85.8%, with an average drop of 79.6%. Comparing the average radiant intensity of different ratios of Mg/PTFE/NC particles, it can be seen that the radiant intensity of Mg/PTFE/NC particles gradually decreases with the decrease of Mg-PTFE mass fraction, when the mass fraction of Mg-PTFE from 30% to 70%, the average radiation intensity increased from 2.64 W•Sr^{-1} to 5.62 W•Sr^{-1}, an increase of 53.2%.

The reaction equation for the combustion of Mg/PTFE/NC agents is known as follows:

$$C_6H_8N_2O_9 \ (s) + \frac{7}{2} O_2 \ (g) = 4H_2O \ (g) + 6CO_2 \ (g) + N_2 \ (g)$$

$$5Mg \ (s) + (C_2F_4) \ (s) + \frac{1}{2} O_2 \ (g) = 2MgF_2 \ (g) + 2C \ (s) + MgO \ (s)$$

Due to the reaction between Mg and PTFE, the characteristic radiation of MgF_2 and MgO is concentrated in the middle and far infrared bands, but the characteristic radiation of NC combustion products H_2O and CO_2 is concentrated in the near and mid-infrared bands, so the mass fraction of Mg-PTFE in the drug is included. The increase in the average radiant intensity of the particles gradually increases. At the same time, according to the Stephen Boltzmann formula [11]:

$$M = \sigma T^4$$  \hspace{1cm} (2)

It can be seen that the radiant energy is proportional to the fourth power of the temperature. Since a large amount of heat is generated during the reaction between Mg and PTFE, the mass fraction of Mg
and PTFE in the powdered Mg-PTFE agent is at least 15% higher than that of the Mg/PTFE/NC agent, so the powdered Mg-PTFE agent, Mg/PTFE The average radiation intensity of the /NC agent decreased by 79.6%.

3.2. Study on Radiation Properties of Different Size Mg/PTFE/NC Particles

Next, the radiation properties of Mg/PTFE/NC particles of different particle sizes were investigated. The table below shows the raw material ratio and particle size of different particle size samples. The mass fraction of nitrocellulose, magnesium powder and polytetrafluoroethylene in the sample is uniformly 50%, 25% and 25%, the difference is that the particle size (here, the value D50) is gradually reduced from 1048.3 μm of sample 6 to the sample 9 of 690.6 μm. The thermal imaging results at different times after burning the sample agent using an infrared camera are shown in Fig. 5. No.0 is a powdery medicament.

Table 4. Radiation intensity of combustion of each sample

| sample | NC / % | Mg / % | PTFE / % | size of particles / um |
|--------|--------|--------|----------|-----------------------|
| 0      | 0      | 50     | 50       | /                     |
| 6      | 50     | 25     | 25       | 1048.3                |
| 7      | 50     | 25     | 25       | 931.1                 |
| 8      | 50     | 25     | 25       | 781.9                 |
| 9      | 50     | 25     | 25       | 690.6                 |

Figure 5. Heat map with varying particle size of Mg/PTFE/NC particles burning with time

It can be seen from Fig. 5 that the radiation area of the stable combustion of the sample 6-9 is also significantly increased compared with the sample No.0, and the burning time is also longer. The radiation area of samples 6-9 has a tendency to decrease, and the overall burning time tends to increase.
From the temperature table on the left, it can be seen that the overall radiant temperature of the sample 6-9 combustion is also lower than the sample No.0. The influence of the particle size of Mg/PTFE/NC sample on the radiation area and radiation intensity will also be described below by numerical calculation.

3.2.1. **Effect of particle size of Mg/PTFE/NC sample on radiation area.** The average radiation area under combustion of each sample was calculated by thermal imaging software as shown in Table 5.

| sample | maximum radiation area $S$ / cm$^2$ | average radiation area $S$ / cm$^2$ | increase ratio / % |
|--------|------------------------------------|------------------------------------|-------------------|
| 0      | 107.78                             | 97.61                              | /                 |
| 6      | 184.56                             | 172.83                             | 77.1              |
| 7      | 164.47                             | 159.23                             | 63.1              |
| 8      | 159.33                             | 153.19                             | 56.9              |
| 9      | 153.35                             | 139.51                             | 42.9              |

It can be seen from the table that the average radiation area of the 6-9 samples is 172.83, 159.23, 153.19, and 139.51 cm$^2$, and the powdery Mg-PTFE agent is 97.61 cm$^2$. The increase of the radiation area is 77.1%, 63.1%, 56.9%, 42.9%, the radiation area increased by an average of 60%, which indicates that the size of the particle size is an important factor affecting the size of the radiation area.

In addition, as the particle size increases, the radiation area of the Mg/PTFE/NC particles tends to increase gradually. When the particle size increased from 690.6 μm to 1048.3 μm, the radiation area increased by 33.32 cm$^2$, an increase of 19.3%. This is because the larger the particle size of the sample particles, the longer the combustion duration of the individual particles, the higher the height achieved by the thrust and the larger the radiation area.

3.2.2. **Effect of particle size of Mg/PTFE/NC sample on radiation intensity.** The calculated radiation intensity versus time for the different particle size Mg/PTFE/NC samples and sample No.0 are as follows. Table 6 shows the radiation intensity at the time of burning each sample.

![Figure 6. Radiation intensity of samples with different particle sizes and sample 0](image)

| sample | radiation duration $t$ / s | average radiation intensity $I$ / W·sr$^{-1}$ | increase ratio / % |
|--------|---------------------------|---------------------------------------------|-------------------|
| 0      | 3.4                       | 18.60                                       | /                 |
| 6      | 3.2                       | 4.56                                        | -75.5             |
| 7      | 3.6                       | 3.64                                        | -80.4             |
| 8      | 3.8                       | 3.61                                        | -80.6             |
| 9      | 6.4                       | 2.89                                        | -84.5             |
Combined with the above chart, the average radiant intensity of the powdered Mg-PTFE agent is 18.60 W•Sr⁻¹, while the average radiance of the sample 6-9 is 4.56, 3.64, 3.61, 2.89 W•Sr⁻¹, respectively. 75.5%, 80.4%, 80.6%, and 84.5%, the overall average decline was as high as 80%. When the particle size of the particles gradually increases, the average radiation intensity generally shows an upward trend, and the duration shows a gradually increasing trend: the particle size increases from 690.6 μm to 1048.3 μm, and the average radiation intensity increases by 1.67 W•Sr⁻¹, 37%, while the sample duration increased from 3.2s to 6.4s.

This is because when the particle size is reduced, the pores between the particles are reduced, and the bulk density between the particles is increased, so that the burning rate of the particles during combustion increases, and more heat is released per unit time, resulting in greater heat radiation. Since the ratio of the raw materials is uniform only between the samples, there is no difference in the characteristic radiation, and the radiation having the larger heat radiation has a larger radiation intensity. Thus, when the formulations are consistent, a reduction in particle size results in an overall decrease in the radiation intensity of the particles.

And because the sample is a column of fuel, it satisfies the Fourier equation:

\[ \alpha = \frac{\lambda}{\rho c} \]  \hspace{1cm} (3)

Where \( \alpha \) is the thermal diffusivity or thermal diffusivity, m²•s⁻¹; \( \lambda \) is the thermal conductivity, W•m⁻¹•K⁻¹; \( \rho \) is the density, Kg•m⁻³; \( c \) is the specific heat capacity, J•Kg⁻¹•K⁻¹. When \( \lambda \) and \( c \) are constant, \( \alpha \) decreases as \( \rho \) increases, so the thermal diffusivity of the column combustion decreases. The most important factor affecting the burning time in the combustion process is the thermal diffusion coefficient, so the burning time of the sample will increase with the decrease of the particle size.

4. Conclusion

(1) The Mg/PTFE/NC particles prepared by the solvent evaporation method have a radiation area increase of 60% and a radiation intensity reduction of 84% compared with the powdery Mg-PTFE agent.

(2) The radiation area of Mg/PTFE/NC particles increases with the increase of particle size. When the particle size increases from 690.6μm to 1048.3μm, the average radiation area increases from 139.51cm² to 172.83cm². A large 19.3%. However, the radiation area of the particles is not affected by the change in the mass fraction of Mg-PTFE.

(3) The radiation intensity of Mg/PTFE/NC particles after burning is related to the mass fraction of Mg-PTFE in the particles and the particle size. When the mass fraction of Mg-PTFE is increased from 30% to 70%, the radiation intensity is increased from 2.64 W•Sr⁻¹ to 5.62 W•Sr⁻¹; when the particle size is increased from 690.6 μm to 1048.3 μm, the average radiation intensity increased from 2.89 W•Sr⁻¹ to 4.56 W•Sr⁻¹.

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