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Effects of Magnesium Powder on the Radiation Characteristics of MTV Foil Infrared Decoys

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Abstract: The aim of this project was to study how the particle size and morphology of magnesium powder affect the burning and infrared radiation characteristics of foil-type Mg/PTFE/Viton (MTV) infrared decoys. A long-wavelength thermal imager and an OPAG33 Fourier transform infrared remote-sensing spectrometer were used to characterize the burning and infrared radiation. The results show that the burning rate, burning temperature, and far-infrared radiation intensity of the decoys are improved significantly with decreased particle size. The burning rate, burning temperature, and far-infrared radiation intensity of the flake-like powder are higher than for the spherical powder of the same particle size.

Keywords: military chemistry and pyrotechnics, infrared decoys, magnesium, burning and infrared radiation characteristics

1 Introduction

Mg/PTFE/Viton (abbreviated to MTV, where PTFE is polytetrafluoroethylene) pyrotechnic composition is widely used in infrared decoys, ignition compositions, incendiary bombs, signal bombs, and solid rocket propellants [1]. MTV is more radiant at near- and medium wavelength bands than the traditional metal/nitrate pyrotechnic compositions [2, 3]. MTV also exhibits high energy, high burning temperature, and high combustion stability [3-5].

However, the burning state and infrared radiation performance of MTV decoys are determined by many factors, such as the pyrotechnic composition, the properties of the raw materials, additives, and the preparative process [6]. Research has shown that an elevated content of Mg powder increases the burning rate exponentially, while the radiant energy is initially increased and then decreased [2, 7]. The infrared radiation intensity of MTVs is maximized at a Mg/PTFE mass percentage of 50/50 [8]. MTV powder pellet (10-20 g) tests proved that the burning rate of MTV decoys increases with decreasing particle size of the Mg powder (this trend is more significant at small particle sizes) and the burning temperature rises in a stepwise manner [6, 9, 10]. Existing research has focused on the effects of the particle size of the Mg powder on the burning state of MTV infrared decoys. In addition, compared with the traditional column-typed MTV decoys, the volume of the foil-typed MTV was smaller, and the combustion temperature and radiance were stronger, resulting in the production of a larger-sized strong radiation cloud. Therefore, in the present study, size-variable flake-like Mg powder and atomized spherical Mg powder were selected and made into MTV foil infrared decoys. We then investigated the effects of the properties of the Mg powder on the radiation performance of the MTV decoys.

2 Experimental

2.1 Main materials

PTFE (3000 mesh) was produced by Shanghai 3F New Materials Co., Ltd. The flake-like Mg powder (100-150 mesh, or 150-200 mesh) and the atomized spherical Mg powder (150-200 mesh, or 200-325 mesh) were produced by Shanghai Longxin Technology Co., Ltd. Fluororubbers were made by Chenguang Fluororubbers Co., Ltd.

2.2 Sample preparation

PTFE and Mg powder were wet-mixed in a mass ratio of 50:50, to give viscous liquids of the same mass ratio, and painted onto 6 × 6 cm foils of tinplate of thickness 1 mm and density 0.9 g/cm^3. The samples mixed with 100- to 150-mesh flake-like Mg powder, 150- to 200-mesh flake-like Mg powder, 150- to 200-mesh spherical Mg powder, and 200- to 325-mesh spherical Mg powder were designated 1#, 2#, 3#, and 4# respectively. A sample is shown in Figure 1.

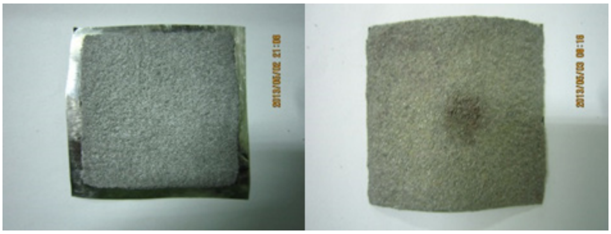
(a) (b)

Figure 1. Diagram of samples (a) without ignition composition, and (b) with ignition composition.

2.3 Instruments

An SC7000 long-wavelength thermal imager (US Flir Systems) operated in the spectral range of 7.7-9.3 μm; resolution of 320 × 240 pixels; temperature resolution < 20 mK; test lens 25 mm; background or atmospheric temperature 16 °C; room temperature 20 °C; emissivity of 1.

An OPAG33 Fourier transform infrared remote-sensing spectrometer (Bruker Corporation, Germany) operated in the spectral range of 4000-400 cm^{-1}; resolution of 4 cm^{-1}; sample and background scanning time of 1 s; the test results are shown in the Emission Spectrograms.

An HCT-2 high-temperature differential thermobalance (Beijing Henven Scientific Instrument Factory) operated from room temperature to 1200 °C, at a heating rate of 10 °C/min and an oxygen flow rate of 50 mL/min.

2.4 Measuring methods

The samples were placed on the test-bed about 1.1 m in front of the lens, and the burning surface was opposite the instrument. After ignition of the surface, the samples were rapidly burnt in a surface-type way. The whole burning process was tested. The spectral distribution of each sample was tested using the OPAG33 spectrometer. The infrared thermograms obtained were analysed using the long-wavelength thermal imager, and the burning time, burning temperature, radiating area, and radiance were computed from the built-in software.

3 Results and Discussion

2.1 Effects of Mg powder on the radiation intensity of infrared decoys

Infrared thermograms illustrating the burning process of decoys 1#-4# were obtained by the long-wavelength thermal imager. Figure 2 shows the burning process of 1# (100 to 150 mesh). Figure 3 shows the infrared thermograms at the highest temperature.

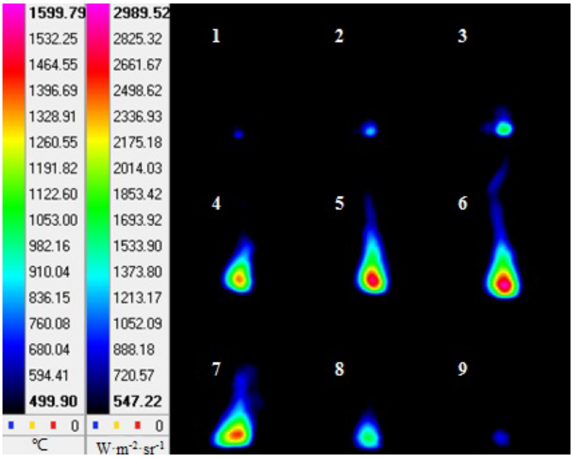

Figure 2. Infrared thermograms illustrating the burning process of 1# (time intervals of 0.5 s).

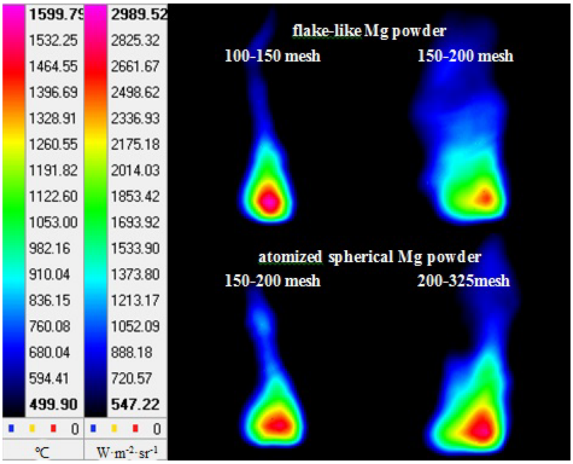

Figure 3. Decoy radiation at the highest temperature.

The built-in software Altair on the long-wavelength thermal imager was used to select data above 500 °C on all of the thermographs. The burning time, burning temperature, radiating area, and radiance were then computed and expressed as mean values. The infrared radiation intensity was computed from the equation , where L is radiance, $W \cdot m^{-2} \cdot sr^{-1}$; A is the infrared radiating area, m^2; θ is the radiation angle, $\theta = 0°$ in this study (Table 1).

Table 1. The burning and infrared radiation intensities of different magnesium decoys

Properties of magnesium		Te [°C]	Burning time [s]	Burning temperature [°C]	Radiance [$W \cdot m^{-2} \cdot sr^{-1}$]	Radiating area [mm^2]	Radiation intensity [$W \cdot sr^{-1}$]
Mesh size of magnesium [mesh]	form of magnesium						
100-150	flake	541.29	5.69	1177.36	1994.56	5936.32	11.84
150-200	flake	533.55	4.84	1177.87	1995.69	8613.48	17.19
150-200	atomization spherical	534.03	6.96	1166.78	1969.52	5942.76	11.70
200-325	atomization spherical	533.93	6.08	1181.59	2003.83	8257.76	16.55

The as-prepared MTV decoys (each type, 5 mg) were placed in an Al_2O_3 crucible, and the thermobalance was used to obtain the TG/DTA curves (Figure 4).

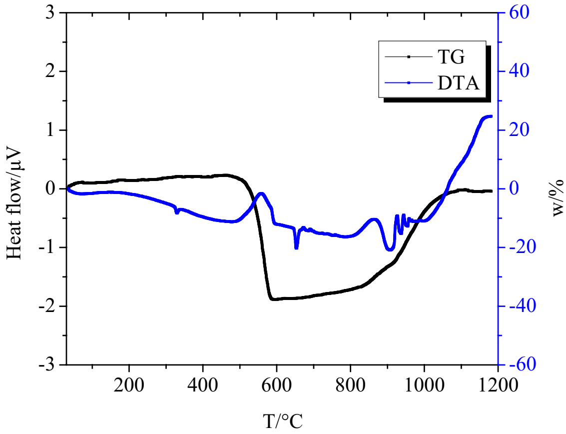

Figure 4. The TG/DTA curves of a MTV decoy.

The DTA curve in Figure 4 shows that PTFE starts to thermally decompose at around 260 °C, is phase transformed at around 326 °C and decomposed to gaseous products. Mg powder begins to melt at around 620 °C, and is phase transformed at about 647 °C. PTFE and Mg powder were burnt out at 950-1000 °C. The TG curve shows that PTFE and Mg powder start to react at 530-540 °C, but the starting temperature changed slightly among the four types of Mg powder (listed in column Te in Table 1). The initial temperature for the flake-like Mg powder (150-200 mesh) and PTFE was at 533.55 °C, which was 7.74 °C lower than for flake-like Mg powder (100-150 mesh) and 0.48 °C lower than for atomized spherical Mg powder. However, the initial temperature of atomized spherical Mg powder (200-325 mesh) was 533.93 °C.

Table 1 shows that a decrease in particle size results in a lower reaction starting temperature, a shorter burning time, and with the radiation intensity increased by 4.85-5.35 $W\cdot sr^{-1}$. The flake-like Mg powder resulted in a higher burning temperature, and a higher radiation intensity compared with the atomized spherical Mg powder of the same particle size. The reasons for this are that the smaller particle size provides a larger specific surface area, and thus a larger contact area for the fluorides (*e.g.* COF_2 and CF_4) generated by decomposition of the PTFE, which favours the formation of more local hotspots. Thus, smaller-sized Mg powder is more likely to react with PTFE, and lead to a lower starting temperature and a shorter burning time. Moreover, the small-sized Mg powder contacts more completely with the PTFE, and thus is more likely to burn completely and to release more heat, causing the burning temperature to rise with decreased particle size [6]. The results in Table 1 are consistent with previous reports [3, 6, 9, 10].

Based on Stefan-Boltzmann's Law, $M = \sigma T^4$ [11], and the definition of radiant emission, $M = \frac{dP}{dA} = \int_{2\pi\ \mathrm{sterad}} L\cos\theta d\Omega$ M ($W\cdot m^{-2}$) [11], we deduced a relationship between the infrared radiance (L, $W\cdot m^{-2}\cdot sr^{-1}$) and the burning temperature (T, K) as: $\sigma T^4 = \int_{2\pi\ \mathrm{sterad}} L\cos\theta d\Omega$

where σ is the Stefan constant. This equation indicates that a major factor affecting the intensity of the infrared radiation is the burning temperature. Thus, small-sized Mg powder is more radiant. The burning and radiation characteristics measured by the long-wavelength thermal imager (Table 2) indicated that the infrared radiating area increased by 2315-2677 mm^2 with the decreased particle size. The reason for this is that when the MTV decoys contains more than 40% Mg, the combustion products are mainly composed of gas-state or liquid-state MgF_2, gas-state Mg, and solid-state C, as well as a small amount of MgF [5]. With the decreased particle size, the Mg powder is burnt more completely to generate more gas-state products, thus forming a larger infrared radiating area. The equation for the intensity of the infrared radiation, $I = L\Delta A\cos\theta$, indicates that this is mainly determined by the infrared radiance and the infrared radiating area, and thus small-sized Mg powder gives a higher radiation intensity.

Similarly, at the same particle size, the flake-like Mg powder, compared to the spherical Mg powder, provides a larger specific surface area and thus a higher radiation intensity.

3.2 Effects of Mg powder on the infrared spectral distribution of decoys

The spectral distribution was tested with a Fourier infrared spectrometer [12], and the results are shown in Figure 5.

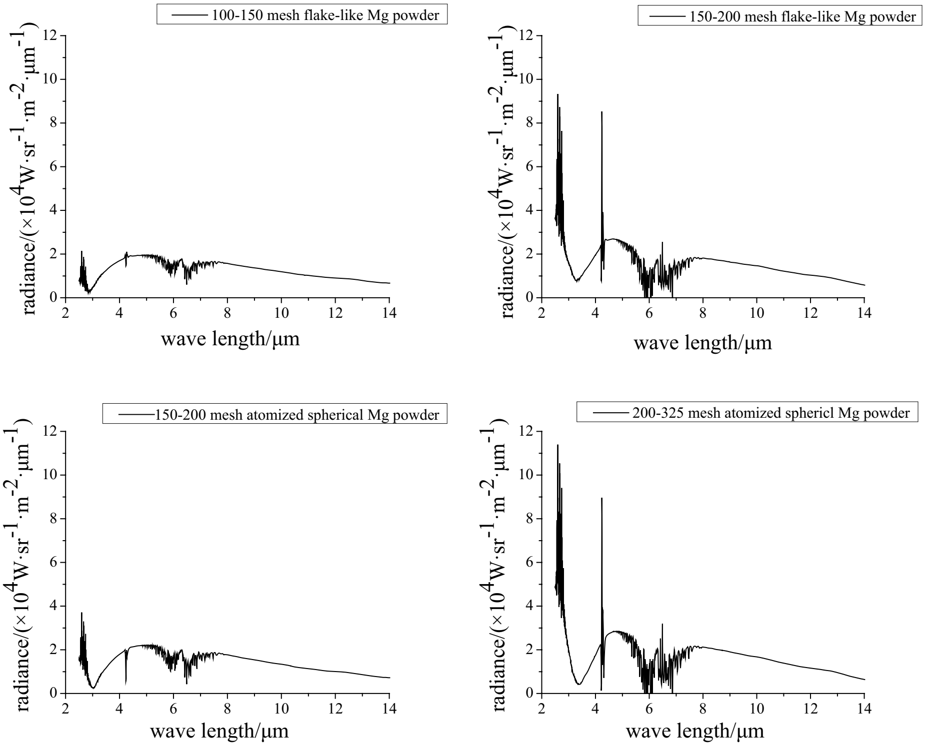

Figure 5. Radiance distribution of the samples.

Clearly, the infrared spectral distributions are basically similar among all of the samples. The near- and medium-wavelength radiation was stronger from small-sized Mg powder or from the flake-like Mg powder of small size.

As reported, PTFE in the atmosphere is thermally decomposed to COF_2, CO_2 and CF_4, while the major products from the PTFE-Mg reaction are MgF, MgF_2, MgO and Mg [4, 5]. The absorption peaks from the chemical database are: CF_4 at 7.8 μm; MgF and MgF_2 at 3.04, 3.50, 6.83 and 7.27 μm; CO_2 at 4.17-4.48 μm; H_2O at 4.63 and 4.81 μm [13, 14]. The small-sized Mg powder, and the flake-like Mg powder at the same size both resulted in a shorter burning time, which means a higher burning rate, and a more complete reaction, which results in a higher product content and density. Thus, the small-sized Mg powder, and the flake-like Mg powder at the same size are both more radiant at near- and medium-wavelength bands. Moreover, according to the Wayne displacement law [11], an increase in temperature, causes the spectral radiation to shift to shorter wavelength. Since the small-sized Mg powder and the flake-like Mg powder at the same size both produce higher burning temperatures, their infrared radiation shifts to near- and medium-wavelength bands.

4 Conclusions

(1) The infrared radiation intensity of both spherical and flake-like magnesium infrared decoys increased with a decrease in particle size.
(2) Because of the larger specific surface area, the flake-like Mg powder, compared to the atomized spherical Mg powder, is more reactive and results in a higher burning temperature, higher radiance, and a higher radiation intensity at the same particle size.

5 References

[1] Koch E.C., Metal-Fluorocarbon-Pyrolants: III. Development and Application of Magnesium/Teflon/Viton (MTV), *Propellants Explos. Pyrotech.*, **2002**, *27*(5), 262-266.
[2] Koch E.C., Dochnahl A., IR Emission Behaviour of Magnesium/Teflon/Viton (MTV) Compositions, *Propellants Explos. Pyrotech.*, **2000**, *25*(1), 37-40.
[3] Koch E.C., Metal-fluorocarbon Based Energetic Materials, Wiley-VCH, Weinheim, 2012; ISBN 978-3-527-32920-5.
[4] Yeh C.L., Mench M.M., Chan S.K., Experimental Study of Flame-spreading Processes over Mg/PTFE/Mg Thin Foils, *Int. J. Energ. Mater. Chem. Propul.*, **1997**, *4*(1-6), 465-475.
[5] Peretz A., Investigation of Pyrotechnic MTV Compositions for Rocket Motor Igniters, *J. Spacecr. Rockets*, **1984**, *21*(2), 222-224.
[6] Zhen L., Pan G.P., Chen X., Qiao L., Effect of Magnesium Powder Particle Size on Combustion Properties of Mg/PTFE Fuel-rich Propellant (in Chinese), *Chin. J. Ener. Mater.*, **2010**, *18*(2),180-183.

[7] Kuwahara T., Matsuo S., Shinozaki N., Combustion and Sensitivity Characteristics of Mg/TF Pyrolants, *Propellants Explos. Pyrotech.*, **1997**, *22*(4), 198-202.

[8] Chen M.H., Ma G.H., Influence of Carbon Fiber on Burning Rate and Infrared Radiation Intensity of Mg/PTFE Infrared Composition (in Chinese), *Laser and Infrared*, **2008**, *38*(10), 1008-1010.

[9] Kubota N., Serizawa C., Combustion of Magnesium/Polytetrafluoroethylene, *J. Propul. Power*, **1987**, *3*(4), 303-307.

[10] Chen M.H., Jiao Q.J., Liu L.B., The Calculation on Burning Rate of Mg/PTFE Infrared Composition (in Chinese), *Initiators Pyrotech.*, **2004**, (3), 5-8.

[11] Zhang J.Q. Fang X.P., *Infrared Physics* (in Chinese), Xian University of Electronic Science and Technology Press, Xian, **2004**; ISBN 978-7-5606-1364-2/O·0069.

[12] Hou W., *The Technology Research of Characteristic of IR/MMW Compound Pyrotechnic Decoy* (in Chinese), Nanjing University of Science and Technology, Nanjing, **2008**.

[13] Zhang L.M., *The Application and Development of Passive Remote Sensing FTIR Technology* (in Chinese), Nanjing University of Science and Technology, Nanjing, **2006**.

[14] Hu J.H., Qin J.F., Shen J.P., A Study on Camouflage Approach against Infrared Imaging Guide (in Chinese), *Infrared Technology*, **2005**, *27*(2), 119-123.