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IMPROVEMENT STUDY OF MAGNESIUM/TEFLON/VITON INFRARED DECOY

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Abstract: The continuous development of infrared guidance technology has imposed higher demands on the performance of infrared decoys. Conventional Magnesium/Teflon/Viton (MTV) infrared pyrotechnic compositions suffer from limited energy output, and airborne platforms carry a relatively limited decoy payload, making it difficult to meet the requirements of long-duration, high-intensity countermeasures. To address this issue, researchers worldwide have conducted extensive modification studies aimed at enhancing the energy output of MTV compositions. This paper systematically summarizes the main approaches and technical methods for MTV composition improvement reported both domestically and internationally, aiming to provide a reference for the development and research of point-source infrared decoys.
Keywords: Pyrotechnics; MTV infrared agents; Combustion; Infrared radiation

1 INTRODUCTION

Infrared guided weapons can detect and recognize the infrared radiation emitted by aircraft, ships, and other platforms, posing a significant threat to the security of these military targets [1-3]. Infrared decoy flares serve as an important countermeasure against infrared guided weapons. Upon combustion, they generate intense radiation in the infrared band that mimics the infrared radiation characteristics of targets such as aircraft and ships, thereby deceiving and jamming infrared guided weapons to protect friendly military assets [4-6].

The most critical component of an infrared decoy flare is its pyrotechnic composition, which plays a decisive role in the decoy's effectiveness. Infrared decoy compositions are mixtures consisting of oxidizers, fuels, and binders, and are mainly classified into seven categories: illuminant type, thermite type, Mg/PTFE type (MTV type), napalm type, thickened triethylaluminum type, white phosphorus type, and aerosol type. Among them, MTV compositions remain widely used to this day owing to their excellent infrared radiation performance.

MTV infrared radiation compositions are composed of magnesium (Mg), polytetrafluoroethylene (PTFE), and fluororubber (Viton). Upon combustion, they produce a high-temperature flame of 2000~2200 K along with incandescent solid particles of C, MgF_2, and MgO, resulting in intense infrared radiation.

With the continuous development of infrared guidance technology, conventional MTV compositions exhibit certain limitations when countering advanced infrared seekers [7-8]. Accordingly, researchers worldwide have conducted extensive modification studies on MTV compositions, aiming to enhance their infrared radiation energy, develop high-energy infrared radiation compositions, and address the issue of insufficient decoy resources on airborne platforms.

2 HIGH-ENERGY FUEL

As the energy source of infrared radiation compositions, the calorific value and reactivity of the fuel play a decisive role in the energy output of the composition. An important approach to enhancing the infrared radiation energy of pyrotechnic compositions is to employ fuels with higher calorific values. Table 1 lists the commonly used fuels in pyrotechnic compositions along with their corresponding calorific values.

Table 1 Calorific Values of Commonly Used Fuels in Pyrotechnic Compositions

Fuel	Heat of Combustion/kJ·mol^{-1}	Mass Calorific Value/kJ·g^{-1}	Volumetric Calorific Value/kJ·cm^{-3}
Mg	602.1	24.7	43
Al	837.5	31.1	83.9
Mg_4Al_3	703	27.9	50.2
B	636.5	58.9	137.7
Si	905	32.3	75.3
Ti	944	19.7	88.8
Zn	350	5.4	38.4

In MTV compositions, metallic magnesium has relatively low melting and boiling points (melting point 650 °C, boiling point 1117 °C) and exhibits good reactivity, but its calorific value is low. Replacing metallic magnesium with fuels of higher calorific value can significantly enhance the infrared radiation energy of the composition.

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Koch substituted Mg in MTV with MgB_2 and Mg_2Si to form MbTV and MsTV compositions, respectively [9]. The infrared radiation performance of these two compositions is summarized in Table 2. As shown in Table 2, the MbTV composition delivers higher radiant energy than MTV in both the α-band (1.8~2.6 μm) and β-band (3.5~4.6 μm); however, it has a lower burning rate and its radiant intensity is inferior to that of MTV. The MsTV composition, by contrast, exhibits a higher radiant intensity than MTV, but burns faster and yields lower radiant energy.

Table 2 Infrared Radiation Performance of MbTV and MsTV Compositions

Component	E_α/J·g^{-1}·Sr^{-1}	E_β/J·g^{-1}·Sr^{-1}	L_α/W·cm^{-2}·Sr^{-1}	L_β/W·cm^{-2}·Sr^{-1}
MTV	180	78	86	37
MbTV-1	141	104	35	26
MbTV-2	155	107	53	36
MbTV-3	159	86	107	58
MsTV-1	111	52	100	47
MsTV-2	121	55	194	88
MsTV-3	117	53	237	108

Koch also replaced Mg in MTV with rare-earth ytterbium (Yb) and compared the radiation performance of three Yb/Teflon/Viton (YTV) formulations with that of MTV (60/35/5) [10]. Although the combustion temperature of YTV is lower than that of MTV, Yb_2O_3 in the combustion products of YTV exhibits a high selective emissivity (0.25~0.35) in the 3.5~4.6 μm band, which is 4~6 times greater than the emissivity of magnesium oxide (0.06) in the same band. Consequently, the YTV formulations outperform MTV in radiant intensity in the 3.5~4.6 μm band.

Chen Minghua et al. substituted magnesium–aluminum alloy for metallic magnesium in Mg/PTFE compositions and investigated the infrared radiation performance of Mg–Al alloy/PTFE compositions at various ratios [11]. When the mass ratio of Mg–Al alloy to PTFE was 70:30, the mid- and far-infrared radiant intensities reached their maxima, at 254.8 W·sr^{-1} and 26.33 W·sr^{-1}, respectively. The specific radiant energy was maximized and energy release was most complete when the mass fraction of Mg–Al alloy ranged from 40% to 50%. The burning rate of the composition increased rapidly with increasing Mg–Al alloy content, and thermal diffusivity was identified as the dominant factor governing the burning rate.

Toan N. Trung et al. selected magnesium–aluminum alloys of different particle sizes (20 μm, 120 μm) and PTFE of different particle sizes (10 μm, 180 μm) to prepare cylindrical grains 35 mm in diameter and 150 mm in length, and investigated their combustion and infrared radiation performance [12]. The results showed that the burning rate increased rapidly once the Mg–Al alloy content exceeded 50%. The combination of fine Mg–Al alloy particles and coarse PTFE particles yielded the highest burning rate, specifically the 20 μm Mg–Al alloy / 180 μm PTFE combination. The infrared radiance peaked at 21.0 W·cm^{-2}·sr^{-1} at an Mg–Al alloy content of 60%, and tended to decrease as the content increased beyond 60%.

Li Jie incorporated red phosphorus (RP) into MTV compositions, which reduced the mass burning rate [13]. The addition of 20% by mass red phosphorus had no significant effect on the combustion temperature or far-infrared radiance, but markedly increased the radiation area (by 141%), thereby enhancing the radiant intensity (by 155%). Figure 1 illustrates the variations in radiation area and radiant intensity with different RP contents in MTV compositions.

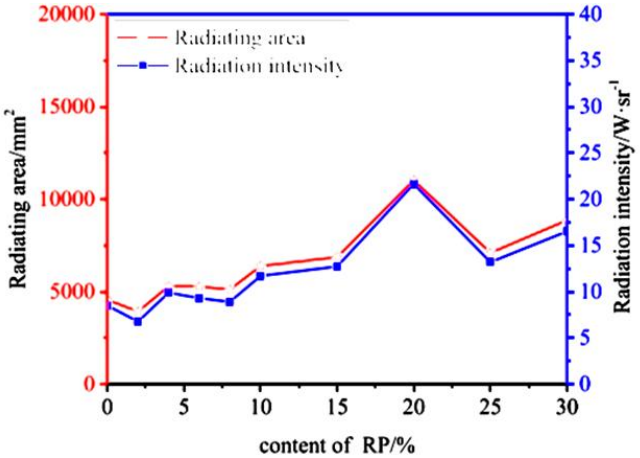


Figure 1 Radiation Area and Radiant Intensity of MTV Compositions with Different RP Contents

3 OXIDIZER

Koch compared several fluorocarbon compounds and found that fluorinated graphite PMF (chemical formula: $(–CF–)_n$) is a superior oxidizer to polytetrafluoroethylene (PTFE) [14]. Upon defluorination, fluorinated graphite yields graphite, whose ultra-high emissivity is conducive to enhancing infrared radiant intensity. Furthermore, fluorinated graphite has a lower enthalpy of formation than PTFE, which translates to a higher heat of combustion upon reaction with magnesium.

Koch conducted comparative tests on the radiation performance of MTV and MPV (magnesium/fluorinated graphite/fluororubber) compositions [15]; the results are presented in Table 3. The MPV composition delivers higher radiant intensity and radiant energy, and the reaction rate between fluorinated graphite and magnesium is also faster. However, fluorinated graphite is prohibitively expensive and remains far from practical production and application.

Table 3 Infrared Radiation Performance of MTV and MPV Compositions

Parameters	MTV	MPV
Mg/wt%	40	40
PTFE/wt%	55	0
PMF/wt%	0	55
Viton/wt%	5	5
$E_{2\sim3\mu m}$/J·g^{-1}·Sr^{-1}	103	170
$E_{3\sim5\mu m}$/J·g^{-1}·Sr^{-1}	80	157
$L_{2\sim3\mu m}$/W·cm^{-2}·Sr^{-1}	72	511
$L_{3\sim5\mu m}$/W·cm^{-2}·Sr^{-1}	56	472

Wang Bing et al. gradually replaced PTFE in Mg/PTFE compositions with Pb_3O_4 and found that the addition of Pb_3O_4 lowered the combustion temperature of MTV [16]. The radiant intensity reached a maximum at a Pb_3O_4 content of 35%. While maintaining the Pb_3O_4-to-PTFE ratio constant and varying the reducing-agent-to-oxidizer ratio [17], they found that both the mass burning rate and radiant intensity were maximized at an oxidizer-to-reducing-agent ratio of 1:1. Having determined the optimal formulation of Mg/PTFE/Pb_3O_4 compositions, Wang Bing investigated the effect of anthracene ($C_{14}H_{10}$) on the radiation performance of Mg/PTFE/Pb_3O_4 infrared decoy compositions [18]. The results showed that the addition of anthracene increased the combustion temperature of the samples; the radiance was maximized at an anthracene loading of 3%, whereas the radiant intensity peaked at 6%.

Sherif Elbasuney et al. synthesized iron oxide nanoparticles with an average particle size of 3 nm via a hydrothermal method and incorporated them into MTV compositions to form composite formulations [19]. The reaction process of the composite compositions was characterized and analyzed. Figure 2 presents the infrared spectra of MTV compositions with varying nano-iron oxide contents. The results indicated that 8% iron oxide nanoparticles enhanced the infrared radiant intensity in the 2~3 μm and 3~5 μm bands by 50% and 85%, respectively. This improvement was attributed to the nano-iron oxide altering the reaction pathway of the composition: the efficient thermite reaction elevated the flame temperature and prolonged the high-temperature reaction zone.

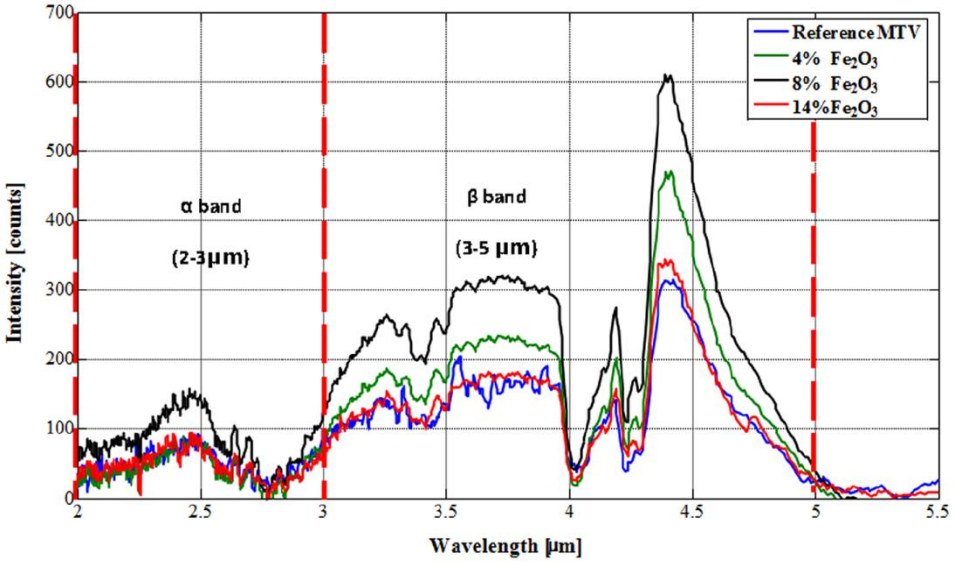


Figure 2 Spectral Comparison Between Composite Compositions and MTV Compositions

Liu et al. prepared nano boron/nickel oxide (B/NiO) thermite and incorporated it into MTV compositions, which increased the mass burning rate and combustion temperature, thereby enhancing the radiant intensity [20]. Du Hui prepared four types of thermites—Al/CuO, Al/NiO, Al/TiO_2, and Al/Fe_2O_3—via a chemical precipitation method [21]. Adding these thermite particles to Mg/PTFE compositions significantly increased both the mass burning rate and linear burning rate, and improved the radiant intensity in the 3~5 μm and 8~14 μm bands. Furthermore, Du Hui prepared five types of aluminum-based mixed metallic fuels by a direct mixing method and incorporated them separately into Mg/PTFE compositions. At relatively low loadings, both the mass and linear burning rates increased and the radiant intensity in the 3~5 μm and 8~14 μm bands was enhanced; at higher loadings, these parameters declined, and a larger quantity of high-temperature molten slag was generated.

4 BINDER

In MTV compositions, fluororubber serves as a binder that not only holds the components together, but also provides a certain oxidizing capability through its fluorine content. In addition to fluororubber, Wang Lei et al. employed nitrocellulose (NC) as the binder for Mg/PTFE compositions and prepared Mg/PTFE/NC granular compositions via a solvent evaporation method [22]. Compared with powdered Mg/PTFE compositions, the radiation area increased by 60%, whereas the average radiant intensity decreased by 80%. Moreover, the radiation area was found to increase with increasing particle size.

5 FUNCTIONAL ADDITIVES

The radiation emitted by burning decoy compositions approximates gray-body radiation, and the emissivity of the combustion products is a key parameter governing the radiation performance. The primary combustion products of MTV compositions—MgF_2 and MgO—exhibit relatively low emissivity. Accordingly, one effective strategy for enhancing the infrared radiant intensity is to raise the emissivity of the combustion products by incorporating high-emissivity materials such as reduced graphene oxide, apatite, and expandable graphite into the composition.

Sherif Elbasuney et al. added reduced graphene oxide (RGO) to MTV and MATV compositions [23]. RGO, with its ultra-high emissivity, can serve as an excellent radiator. Figure 3 presents the radiant intensity of MTV and MATV compositions at various RGO loadings. At an RGO content of 6%, the radiant intensity in the 2~5 μm band increased by 147% and 82% for MTV and MATV compositions, respectively. Subsequently, Sherif Elbasuney incorporated a graphite/nano-Fe_2O_3 composite into MTV compositions [24]. The nano-Fe_2O_3, possessing ultra-high reactivity, undergoes a thermite reaction with magnesium in the MTV composition, releasing a substantial amount of heat; meanwhile, graphite, owing to its ultra-high emissivity, functions as an ideal infrared radiation source. The synergistic effect of the two greatly enhanced the radiant intensity of the MTV composition. The optimal ratio of the graphite/nano-Fe_2O_3 composite was found to be 6% graphite and 2% nano-Fe_2O_3, which boosted the radiant intensity of MTV in the 2~5 μm band by 248%.

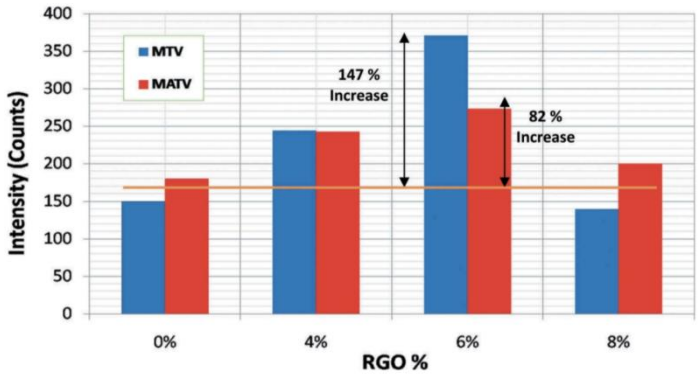


Figure 3 Radiant Intensity of MTV and MATV Compositions Incorporated with Reduced Graphene Oxide

Hesham Tantawy et al. adopted an approach similar to that of Sherif Elbasuney, incorporating ferric oxide (Fe_2O_3) and hydroxyapatite (HA) into MTV compositions [25]. Under the combined effect of the high emissivity of HA and the high heat release from Fe_2O_3, the radiant intensity of the composition in the 2~5 μm band increased by 97%. In addition, the phosphorus contained in HA was beneficial for improving the spectral performance of the MTV compositions.

Gao Yong et al. added urotropine to MTV compositions and found that the burning duration was prolonged [26]. The endothermic decomposition of urotropine lowered the combustion temperature, while the strong selective radiation of CO_2—a combustion product—at 4.3 μm enhanced the radiant intensity of the composition in the 3~5 μm band.

Liu Hui et al. prepared $MnFe_2O_4$ infrared ceramics via a solid-state sintering method and incorporated them into MTV decoy compositions [27]. The results showed that the combustion temperature of the composition decreased, but the characteristic radiation from the infrared ceramics improved the radiance in the 3~5 μm and 8~14 μm bands.

6 CONCLUSION

Addressing the limitations of MTV compositions, this paper elaborates on the technical approaches for MTV modification from the perspective of energy enhancement. The adoption of high-energy raw materials and high-emissivity additives can further enhance the radiant energy of MTV compositions by elevating the combustion temperature, expanding the radiation area, and increasing the emissivity of the combustion products. By summarizing the specific methods employed in domestic and international research on MTV composition improvement, this paper aims to provide a reference for the advancement of point-source infrared decoys and to enhance their capability to counter advanced infrared guided weapons.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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