Central European Journal of Energetic Materials
ISSN 1733-7178; e-ISSN 2353-1843

Cent. Eur. J. Energ. Mater. 2021, *18*(4): 529-544; DOI 10.22211/cejem/145383
Article is available in PDF-format, in colour, at:
https://ipo.lukasiewicz.gov.pl/wydawnictwa/cejem-woluminy/vol-18-nr-4/

Research paper

Investigation of the Ignition of MTV Decoy Flares

Andrzej Orzechowski*,1), **Marcin Nita**1), **Dorota Powała**1), **Mariusz Pietraszak**2), **Tomasz Klemba**2), **Andrzej Maranda**3)

1) *Military Institute of Armament Technology, 7 Prymasa Stefana Wyszyńskiego Street, 05-220 Zielonka, Poland*
2) *Air Force Institute of Technology, 6 Księcia Bolesława Street, 01-494 Warsaw, Poland*
3) *Łukasiewicz Research Network - Institute of Industrial Organic Chemistry, 6 Annopol Street, 03-236 Warsaw, Poland*
* *E-mail:* orzechowskia@witu.mil.pl

Abstract: Mg/Teflon®/Viton (MTV) flares are the pyrotechnic compositions used in infrared decoys to protect aerial targets from IR-guided missiles. In this study, the influence of formulation changes on the burning time, and on the time to reach the required level of intensity of infrared radiation was examined. An ignition, in particular the quantity of ignition mixture used, and the ignition surface has a significant influence on the tested parameters. For charges with a density of 1.7 g/cm^3 and a mass of approx. 40 g, it was possible to obtain the required rise time and intensity of radiation after applying about 5 g of the igniting mixture. The ratio of the grooved area, with the ignition mixture on the lateral surface of the pellet, to the total lateral surface of the pellet was approx. 0.6.

Keywords: decoy flare, MTV, pyrotechnics, ignition

1 Introduction

Military aircraft emit infrared (IR) radiation at different wavelengths. The aircraft main radiation sources are the hot jet engines (2-3 µm), the exhaust plume (3-5 µm) and the heated fuselage (8-10 µm) [1, 2]. The IR radiation from a military helicopter has been presented by Rohacs *et al.* [3]. IR guided missiles track heat sources emitted by the target and therefore are one of the major threats to military aircraft. Different IR guided missiles, such as Stinger, Strela, and Igla, have been developed around the world. A typical IR seeker (2-3 µm) has a photoconductive detector containing PbS [4, 5]. More advanced seekers containing InSb in the detector have a value 3-5 µm. IR detector countermeasure systems play an important role in countering these threats [4-7].

The radiant emittance (W) of a radiating body is described by Planck's law. This law is true for a black body. Actual radiators are called grey bodies. In order to describe the deviation of radiation from ideal behaviour, the term emissivity has been introduced (Equation 1).

$$\varepsilon = W'/W \tag{1}$$

where ε is emissivity, W' is the radiant emittance of the actual radiator (grey body) (in $\text{W·cm}^{-2}\ \mu\text{m}^{-1}$) and W is the radiant emittance of a black body (in $\text{W·cm}^{-2}\ \mu\text{m}^{-1}$).

The characteristics of the generated IR radiation depends on the properties of the object, that is radiating. When that object is a decoy flare, the most important parameters are the wavelength of the emitted radiation, the amount of heat that is released during burning and the rate of heat release.

The atmosphere has a window where infrared transmission is high and relatively uniform. Several detectors exist whose spectral response peaks in this transmission band. Therefore, a convention has emerged that categorizes missiles by the band: α (2-3 µm) and β (3-5 µm). The Plank function can be used to determine the efficiencies of difference sources. Lower temperature-sources are more efficient, but the radiance level produced by higher temperature-sources is greater [8].

A useful parameter for estimating a decoy flare's spectral performance is the intensity ratio (θ), which is the ratio of the average emission intensity in the α-band (2-3 µm) to that in the β-band (3-5 µm):

$$\theta = I\alpha/I\beta \tag{2}$$

A comparison of the IR emission spectrum of a charge composed of the pyrotechnic composition based on Mg, Teflon® and Viton (MTV) and target is shown in Figure 1. The thermal signature of the aircraft is shown in Figure 2.

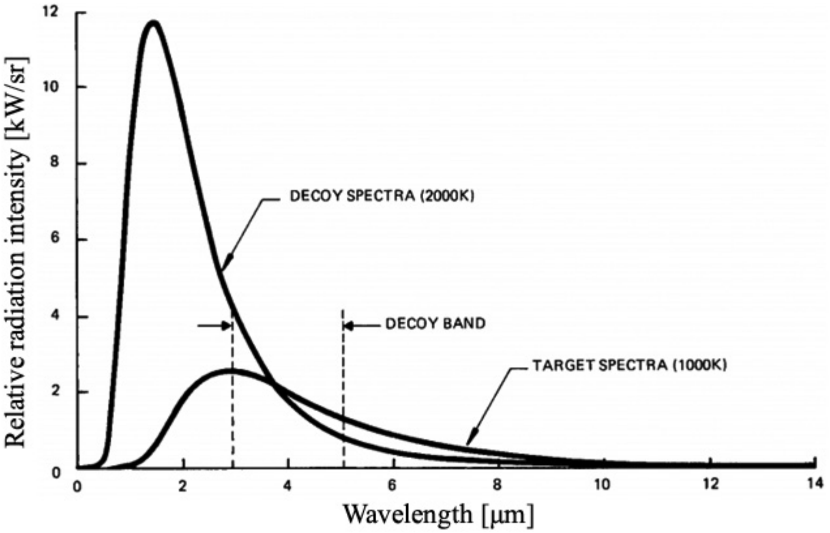

Figure 1. Comparison of MTV and target radiant intensities [8]

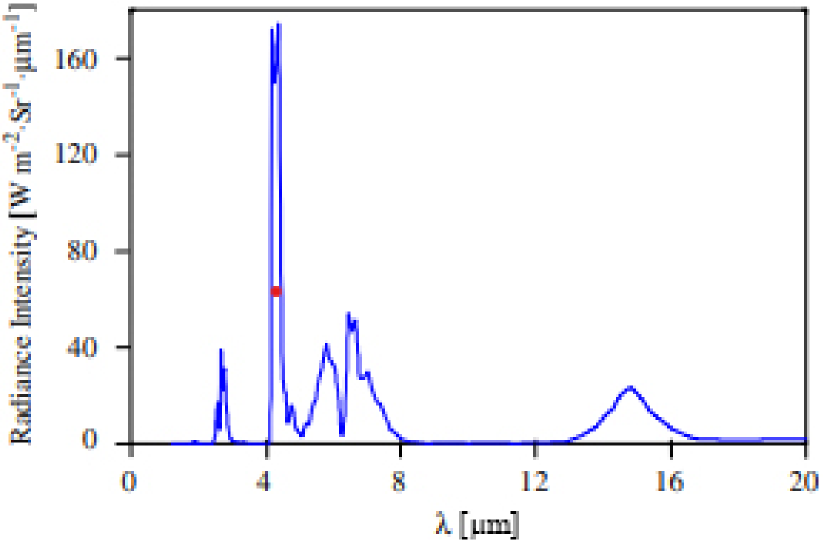

Figure 2. Spectral radiance intensity of an aircraft plume [2]

MTVs are widely used in infrared decoys [1-4]. MTV is more radiant at near and medium wavelength bands than traditional pyrotechnic compositions. They are effective against IR missiles, especially of the first generation. The initial combustion stage of an MTV mixture can be described according to the following Reaction R1.

$$m\mathrm{Mg} + \text{–}(\mathrm{C_2F_4})\text{–} \rightarrow 2\mathrm{MgF_2} + (m-2)\mathrm{Mg} + 2\mathrm{C} + h\nu \qquad \text{(R1)}$$

The MTV combustion reaction requires consideration of the oxygen provided by the atmosphere. This causes afterburning of the vaporized Mg and carbonaceous particles. The heat generated during this combustion raises the temperature of carbon black to around 2200 K, emitting IR radiation similar to a black body in the range 1-3 µm.

Mg rich compositions yield extra energy by atmospheric oxidation of the vaporized Mg, increasing the reaction temperature to 3100 K. In addition, carbon oxidized to CO_2 increases the radiant emittance (3-5 µm).

$$m\mathrm{Mg} + \text{–}(\mathrm{C_2F_4})\text{–} + \mathrm{O_2} \rightarrow 2\mathrm{MgF_2} + (m-2)\mathrm{MgO} + 2\mathrm{CO_2} + h\nu \qquad \text{(R2)}$$

MgO behaves like a grey body with spectral emissivities in the ranges 2.8-4 µm ($\varepsilon = 0.08$) and 4-8 µm ($\varepsilon = 0.38$) [1]. The main combustion products MgF_2 and MgO have emissions in the ultraviolet. This example shows how the reaction products determine the spectral characteristics of an MTV composition.

A theoretical study of the combustion of MTV is presented in [13]. The maximum reaction temperature and the maximum heat of reaction occur near the stoichiometric MTV composition (33% Mg). The combustion products change as the percentage of Mg in the composition is changed. If the formulation is fuel lean (<20% Mg), the major reaction products are $C_{(s)}$, $CF_{4(g)}$, $MgF_{2(l)}$, $MgF_{2(g)}$ and small amounts of $CF_{2(g)}$ and $HF_{(g)}$. As the percentage of Mg in the MTV is increased, there are several changes in the equilibrium reaction products, between $MgF_{2(g)}$ and $MgF_{2(l)}$. The amount of liquid MgF_2 increases, the volume of $CF_{4(g)}$ decreases, but the mass of $C_{(s)}$ is almost constant. For the fuel rich compositions (>40% Mg), the major reaction products are $MgF_{2(g)}$, $MgF_{2(l)}$, $MgF_{(s)}$ and $C_{(s)}$. $Mg_{(g)}$ and $Mg_{(l)}$ are formed from unreacted Mg. The mass fraction of $C_{(s)}$ decreases from approximately 15 to 6% because the Teflon® content is lower. The presence of $Mg_{(g)}$ and $Mg_{(l)}$ confirms that the formulation is rich in fuel. A significant amount of MgO begins to form only when the amount of air exceeds approximately 60% of the total reactants. The $C_{(s)}$ content in the combustion products decreases when the amount of air increases and disappears at approximately 50% air (50% MTV) due to the reaction:

$$3C + 2O_2 \rightarrow 2\,CO + CO_2 \qquad \text{(R3)}$$

The use of 54% Mg for the standard MTV decoy flare is to achieve a high burn rate and high ignitability [6]. Compositions containing 58% Mg and 4% Viton can be used to ignite propellant in test rocket motors [7]. An exponential increase in the burning rate with increasing Mg weight fraction is observed [9]. The influence of Mg content on the intensity of radiation depending on the wavelength is presented in [15, 16].

Du *et al.* [17] investigated the influence of granulometric form and grain size characteristics of Mg on the parameters of the Mg-polytetrafluoroethylene (PTFE) compositions. The IR radiation intensity of compositions with spherical and flake-like Mg powder increases when the particle size is decreased. Kubota and Serizawa [18] observed that the burning rate increases with an increase in the surface area of the Mg particles.

Adhikary *et al.* [19, 20] have studied the influence of process parameters on the mechanical properties of MTV. As the charge mass is compressed, the finer particles are pushed into the voids between the larger particles. Increasing the applied load causes an increase in the density and the burning time of the charge. The IR intensity decreases as the applied load is increased due to a decrease in the effective combustion area. Increasing the applied load causes plastic deformation and particle fragmentation, resulting in a maximum density for a given load. In order to obtain the maximum density and compressive strength of charges, Taguchi's experimental optimization method [21, 22] can be used, in which several process parameters, *i.e.* applied load, compression time and charge mass, are analysed.

Often the problem with investigating decoy flares is to obtain the desired operating parameters, such as radiation intensity, burning time, time to reach the maximum intensity, and density, ensuring good mechanical properties. The present authors have investigated the influence of the ignition parameters on the characteristics of the pellets, which has not been described in detail in the literature for MTV flares.

The aim of the study was to investigate the effect of the type, quantity and proportions of the components used in the pyrotechnic mixture, as well as the location of the ignition mixture on the burning time, radiation intensity and the time to reach the desired intensity.

2 Materials

The ingredients of the pyrotechnic compositions prepared for investigation were Mg, PTFE, Viton, and additive pyrolytic carbon, used in only one composition. The chemical compositions of the formulations are shown in Table 1. The composition of the ignition mixture was 53% Mg, 40% Teflon®, 7% Viton.

Table 1. Chemical composition of the prepared formulations

Component	Content [%] in formulation			
	C2	C3	C4	C7
Mg (<106 µm)	63.0	38.0	67.0	66.0
Mg (106-180 µm)	–	25.0	–	–
Teflon®	20.0		23.0	23.0
Viton	17.0		10.0	9.5
Pyrolytic carbon (<50 µm)	–	–	–	1.5

The preparation of the formulations consisted in dissolving 1 g Viton in 5 mL ethyl acetate. The mixture of Mg powder and PTFE was then added to the resultant solution. The mixture was dried and granulated through a sieve of 300 µm to obtain uniformly sized particles.

The formulations were pressed with a hydraulic uniaxial press into cylindrical pellets with a diameter of 25 mm (Figure 3). Before pressing, an appropriate sample of the pyrotechnic mixture was conditioned for approx. 1 h at 70 °C. The prepared mixture was then filled into the mould, which was also previously held at 70 °C. The mixture was pressed to the desired height, *i.e.* approx. 47 mm. The pressure on the sample area (4.91 cm^2) was about 7 tons and was maintained for 30 s. Longitudinal and transverse grooves were milled on the surface of the pellets (Figure 4). The ignition mixture was placed into the longitudinal and transverse grooves of the pellet (Figure 5). Each pellet`s mass was approximately 40 g. Charges with the ignition mixture were placed in aluminium foil and ignited by an electric igniter.

Figure 3. Pressed pellet

Figure 4. Pellets with grooves

Figure 5. Pellet with ignition mixture

3 Test methods

The radiative emission of the tested charges was recorded using an infrared camera FLIR SC6000 HSDR.

4 Results and Discussion

A charge of a specific shape can be obtained by pressing the mixture into a previously made mould. Since the production of a mould is time-consuming and expensive, and it is not always possible to obtain the desired shapes by the press method, the charges were obtained by machining previously prepared pellets. Therefore, it was necessary to perform exploratory tests on the mechanical sensitivity of the compositions. Table 2 lists the results of the impact and friction sensitivity tests. The compositions were characterized by low friction and impact sensitivity, >360 N and 30 J, respectively. These results allowed the pellet milling operation to be conducted in a relatively safe manner.

Table 2. Sensitivity to mechanical stimuli of the MTV compositions

Composition	Friction sensitivity [N]	Impact sensitivity [J]
C2	>360	30
C3	>360	30

When developing a flare pellet, the main parameters of the charges should be optimized. In the present work, the following desired flare parameters were assumed:

- radiation intensity: 2 kW/sr,
- time to reach the desired intensity: min. 0.2 s, and
- burning time: min. 3 s.

For the assumed geometry of the charge, the radiation intensity and extent of combustion time can be increased by means of different methods. This is possible mainly by using Mg with different particle sizes, as well as using additives that influence the combustion rate, adjusting the density, increasing the amount of ignition mixture, and its contact surface with the pellet.

In order to investigate the effect of the ingredients used, on the burning time and the time to reach the desired intensity, charges that differed in the particle size of Mg, density, and amount of ignition mixture, were prepared. The experimental data obtained are presented in Table 3. The composition of the ignition mixture was the same for all pellets.

Table 3. Influence of the mass of the ignition mixture on the time to reach the maximum intensity and burning time

Composition	Ignition mixture [g]	Density [g/cm^3]	Radiation intensity [kW/sr]	Time to reach the max. intensity [s]	Burning time [s]
C2	2.5	1.73	2.3	0.9	2.6
	4.5	1.73	3.9	0.09	2.2
C3	2.5	1.73	2.2	1.4	7.0
	3.5	1.73	2.6	0.6	6.7
	4.5	1.73	3.8	0.18	6.4
	7.0	1.73	4.4	0.09	6.2
	2.5	1.52	2.2	0.7	4.4
	3.5	1.52	2.8	0.21	3.3
	4.5	1.52	3.3	0.1	2.9
C4	2.5	1.73	1.9	0.9	5.0
C7	2.5	1.73	2.0	0.8	4.0

The important parameter is the time to achieve the desired radiation intensity, which should be about 0.2 s. Too long a rise time to the maximum intensity level of the radiation reduces the effectiveness of the flares, and also affects the efficiency of the main charge and affects the burning time and intensity of the radiation. In order to investigate the impact of the above-mentioned parameters on the time to reach the assumed intensity of radiation, pellets from the mixtures of C2 and C3 compositions were prepared. The prepared pellets had different densities and variable amounts of the ignition mixture on the lateral surface, connected with the necessity to increase the contact surface of the igniting mixture with the lateral surface of the pellet. This was achieved by making a larger number of grooves for placing the igniting mixture on the surface of the charge (Figure 4). This resulted in differences in the mass of the pellets caused by the decrease in the mass of the pyrotechnic mixture. Figure 6 shows an example of a C2 formulation with a long time to reach the maximum intensity of radiation, despite the fine Mg used in this composition, which is less significant than the amount of the ignition mixture. An increase in the amount of ignition mixture resulted in achieving the desired level of the above-mentioned parameter for C3 composition (Figure 7).

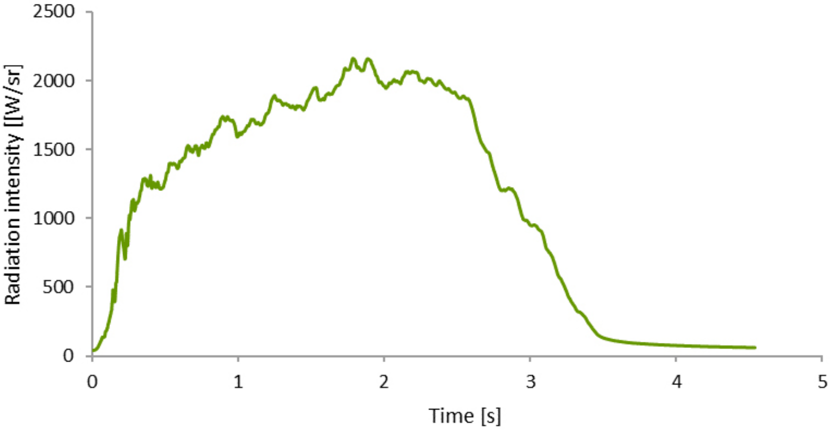

Figure 6. Radiation intensity of the C2 composition

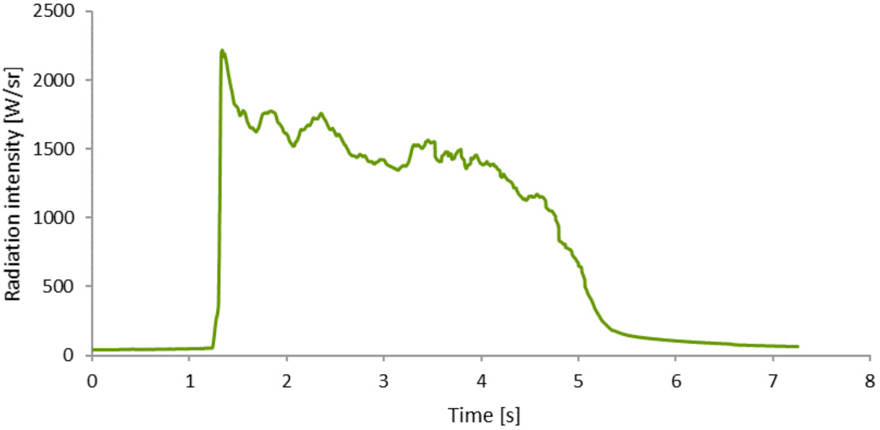

Figure 7. Radiation intensity of the C3 composition

The effect of the amount of ignition mixture used on the time to reach the desired radiation intensity is shown in Figure 8. The optimal amount of the ignition mixture required depends on the charge density for a particular composition. For pellet masses of approx. 40 g, with a density of 1.73 g/cm^3, a larger amount of the igniting mixture, about 5 g, is needed than for pellets of density 1.52 g/cm^3, where 3.5 g is sufficient. The contact of the igniting mixture with the pellet surface is related to the addition of extra grooves in which the igniting mixture can be permanently placed.

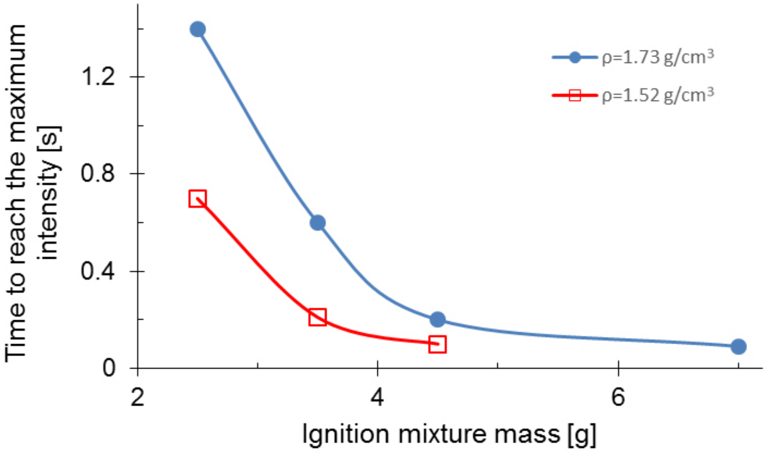

Figure 8. Effect of ignition mixture mass on the time to reach the maximum intensity

The influence of the contact surface of the mixture in relation to the total lateral surface, on the radiation intensity is shown in Figure 9. The desired value of the radiation intensity for the C3 composition with a density of 1.73 g/cm^3, having two different fractions of Mg particles, was obtained for a value of 0.67 for the ratio of the contact surface of the ignition mixture to the total lateral surface.

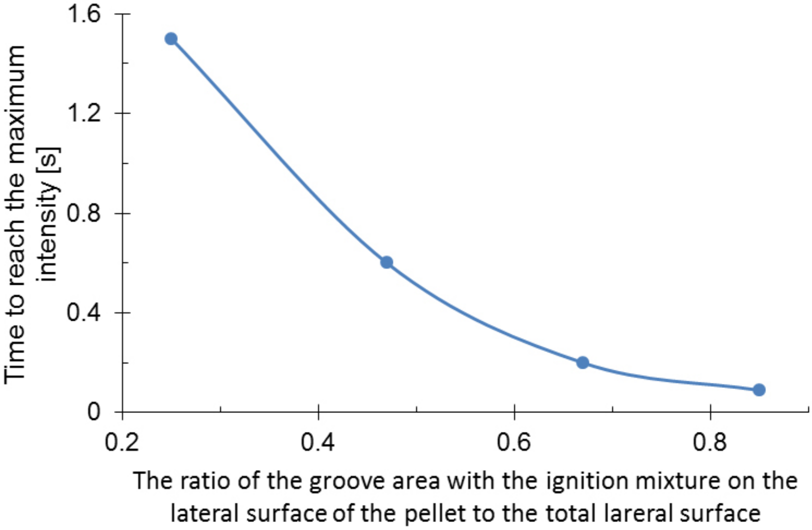

Figure 9. Influence of the ratio of the ignition mixture contact area to the pellet (ρ = 1.73 g/cm^3) side surface on the time to reach the maximum intensity

The amount of the igniting mixture slightly affects the burning time of the charge, as shown in Figure 10. An increase in the amount of the igniting mixture decreases the burning time, especially for lower densities. An increase in the burning rate can be achieved by the addition of pyrolytic carbon. The C7 composition, with a density of 1.73 g/cm^3, exhibits a 20% decrease in burning time compared to the C4 composition with the same density (Table 3).

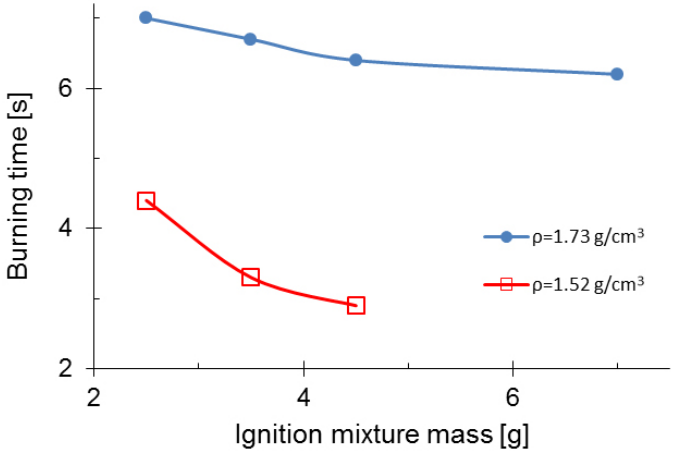

Figure 10. Effect of ignition mixture mass on the burning time of the charge

As the amount of the ignition mixture is increased, the intensity of the radiation increases as shown in Figure 11. A similar intensity was obtained for different densities for the C3 composition. This is due to the fact that the mixture with a lower density has a higher burning rate, for the same volume of pellet. This indicates that a sample with lower density is more porous, which allows better access of oxygen to the surface of the combustible solid. Achieving the desired radiation intensity rise time is possible mainly by burning the ignition mixture. The amount of the ignition mixture and the contact surfaces with the pellet to achieve a set time to reach the desired intensity of radiation should be chosen, and then adjusted to produce the desired radiation intensity of the charge.

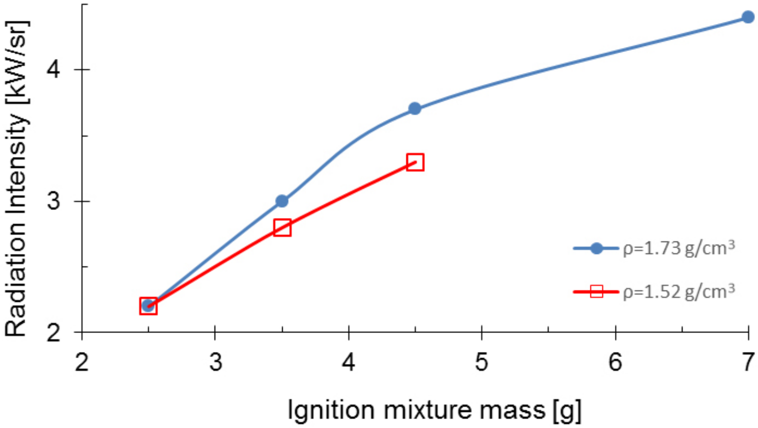

Figure 11. Effect of ignition mixture mass on the radiation intensity of the charge

5 Conclusions

♦ The results have shown that both the presence of smaller magnesium particles in the mixture and a reduction in the charge density increases the intensity of the emitted radiation, but reduces the charge burning time.

♦ It is difficult to obtain radiation with the desired intensity, *e.g.* 2 kW/sr in the first 200 ms with the assumed parameters, *i.e.* minimum burning time of 3 s, pellet weight 40 g, and density to ensure a specific mechanical strength. By increasing the contact surface of the ignition mixture with the pellet surface, the rate of ignition of the charge was increased. Obtaining the required radiation intensity and time to reach maximum intensity was possible after applying about 5 g of the igniting mixture on the pellet surface, at a ratio of the contact surface of the igniting mixture to the total side surface of the charge of 0.67.

♦ The desired parameters were achieved for sample C3 containing more than 4.5 and 7 g of the ignition mixture. The tailored amount of the ignition mixture results from its adjustment to give a specific time to reach the maximum intensity, and to the radiation intensity of the basic mixture.

References

[1] Mahulikar, S.P; Rao, G.A.; Sonawane, H.R.; Prasad, H.S.S. Infrared Signature Studies of Aircraft and Helicopters. *Proc. Progress in Electromagnetics Research Symp. 2009*, Vol. 1, Moscow, Russia, **2009**, 15-19.

[2] Mahulikar, S.P.; Rao, G.A.; Sane, S.K.; Marath, A.G. Aircraft Plume Infrared Signature in Nonafterburning Mode. *J. Thermophys. Heat Transf.* **2005**, *19*(3): 413-415.

[3] Rohacs, J.; Jankovics, I.; Gal, I.; Bakunowicz, J.; Mingione, G.; Carozza, A. Small Aircraft Infrared Radiation Measurements Supporting the Engine Airframe Aero-thermal Integration. *Period. Polytech. Transp. Eng*. **2019**, *47*(1): 51-63.

[4] Clancy, T. *Fighter Wing: A Guided Tour of an Air Force Combat Wing*. Vol. 3, Penguin Books, **2007**.

[5] Koch, E-C.; Dochnahl, A. Investigation of Combustion Process in Magnesium/Teflon/Viton (MTV) Compositions by Emission Spectroscopy. *Proc. 30th Int. Annual Conf.,* Karlsruhe, Germany, **1999**, P-87.

[6] Koch, E. Review on Pyrotechnic Aerial Infrared Decoys. *Propellants Explos. Pyrotech*. **2001**, *26*(1): 3-11.

[7] Koch, E.; Hahma, A.; Weiser, V.; Roth, E.; Knapp, S. Metal-fluorocarbon Pyrolants. XIII: High Performance Infrared Decoy Flare Compositions Based on MgB_2 and Mg_2Si and Polytetrafluoroethylene/Viton®. *Propellants Explos. Pyrotech*. **2012**, *37*(4): 432-438.

[8] *The Infrared & Electro-Optical Systems Handbook. Countermeasure Systems*. Vol. 7, (Pollock, D.H.; Accetta, J.S.; Shumaker, D.L., Eds). Ann Arbor: MI, Infrared Information and Analysis Center and Bellington, WA, SPIE Optical Engineering Press, **1993**.

[9] Koch, E.; Dochnahl, A. IR Emission Behaviour of Magnesium/Teflon/Viton (MTV) Compositions. *Propellants Explos. Pyrotech.* **2000**, *25*(1): 37-40.

[10] Hahn, G.T.; Rivette, P.G.; Weldon, R.G. *Infra-red Tracking Flare*. US Patent 5679921, **1997**.

[11] Douda, B.E. *Genesis of Infrared Decoy Flares. The Early Years from 1950 into the 1970s.* NSWC/CCR/RDTR-08/63. Crane, IN, **2009**.

[12] Earle, M.D. Infrared Countermeasures Techniques. In: *Electronic Countermeasures*. (Boyd, J.A.; Harris, D.B.; King, D.D.; Welch H.W., Eds) Los Altos Hills, CA, Peninsula Publishing, **1978**.

[13] de Yong, L.V.; Smit, K.J. *A Theoretical Study of the Combustion of Magnesium/Teflon/Viton Pyrotechnic Compositions.* Materials Research Laboratory, Technical Report MPL-TR-91-25. Marybirnong, Victoria, Australia, **1991**.

[14] Peretz, A. Investigation of Pyrotechnic MTV Compositions for Rocket Motor Igniters. *J. Spacecr. Rockets* **1984**, *21*(2): 222-224.

[15] Elsaidy, A.; Kassem, M.; Tantawy, H.; Elbasuney, S. The Infrared Spectra of Customized Magnesium/Teflon/Viton (MTV) Decoy Flares to Thermal Signature of Jet Engine. *Proc. 17th Int. Conf. Aerospace Sciences and Aviation Technology*.

Cairo, Egypt, **2017**, paper ASAT-17-103-CA.

[16] Elbasuney, S.; Elsaidy, A.; Kassem, M.; Tantawy, H.; Sadek, R.; Fahd, A. Infrared Spectra of Customized Magnesium/Teflon/Viton Decoy Flares. *Combust. Explos. Shock Waves* **2019**, *55*(5): 599-605.

[17] Du, J.; Guan, H.; Li, J. Effects of Magnesium Powder on the Radiation Characteristics of MTV Foil Infrared Decoys. *Cent. Eur. J. Energ. Mater*. **2015**, *12*(4): 855-863.

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

[19] Adhikary, S.; Sekhar, H.; Thakur, D.G. Investigations of Process Parameters on the Mechanical Properties of MTV Decoy Flare Pellets for Defence Applications. *Procedia Structural Integrity* **2019**, *14*: 127-133.

[20] Adhikary, S.; Sekhar, H.; Thakur, D.G. Performance Evaluation of Mechanically Pressed Magnesium/Teflon/Viton (MTV) Decoy Flare Pellets. *Sadhana* **2020**, *45*(45): 1-6.

[21] Adhikary, S.; Sekhar, H.; Thakur, D.G. Optimization of Compressive Strength of MTV Decoy Flare Pellets by Taguchi Method. *Particul. Sci. Technol*. **2020**, (March): 1-6.

[22] Adhikary, S.; Sekhar, H.; Thakur, D.G. Optimization of Density of Infra-red Decoy Flare Pellets by Taguchi Method. *Sadhana* **2019**, *44*(160): 1-9.

Received: March 16, 2021
Revised: December 28, 2021