Metal–Fluorocarbon Pyrolants: IX.† Burn rate and Radiometric Performance of Magnesium/Teflon/Viton (MTV) Modified with Zirconium

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Abstract: *The burn rate, u (mm s^{-1}) of fuel rich magnesium/Teflon/Viton (MTV) is increased by 65% upon addition of zirconium whereas the spectral efficiency Eβ (J g^{-1} sr^{-1}) is reduced by 15%.*

Keywords: *Burn rate, zirconium, magnesium, MTV, polytetrafluoroethylene, radiometry, Teflon™, Viton™*

Metal–fluorocarbon pyrolants such as MTV play an important role as both igniter materials for rocket propellants (type N-35)[1,2] and infrared decoy flares to protect flying platforms.[3–5] Recently the author reported the increase in the burn rate of MTV upon addition of graphite.[6] Another method for modifying the burn rate of MTV has been disclosed by Kuwahara and Ochiai. They observed an increase in the burn rate of fuel rich MTV (65/30/5) upon the addition of zirconium.[7]

However it is unclear if the addition of zirconium to MTV would also affect the spectral efficiency of such compositions. Hence in the present investigation a fuel rich MTV composition (65/30/5) was modified with various amounts of zirconium.

The compositions were prepared in 500 g batches with conventional mixing in a 0.5 l blender. The following materials were used: magnesium (non ferrum Metallpulver, A-5111 St. Georgen, ECKA Mg-Pulver LNR-61, mean particle radius 20 µm), PTFE (Dyneon, D-84505 Burgkirchen, TF-9205, mean particle radius: 2 µm), Viton (Mach I Inc. King of Prussia, USA, FC-2175), zirconium (Chemetall GmbH, Special Metals Division, D-60487 Frankfurt, Zirconium-GH, Blaine mean particle size 5.5 µm). Magnesium and zirconium were wetted with acetone and mixed in a blender until a uniform grey mass resulted. Addition of PTFE powder and Viton dissolved in acetone followed. The mass was mixed until small granules had formed. These were screened through a 3.5 mm sieve and dried on stainless steel drying pans at reduced pressure at 40 °C for 12 h.

The compositions were pressed in a 24.5 mm cylindrical die with 250 MPa pressing pressure and 6 s hold time to give consolidated strands of ~39 g mass and ~42 mm height. The lateral surfaces of the strands were painted with polyurethane lacquer and to the top face was applied an ignition dip from a boron, potassium nitrate, nitrocellulose (12/84/4) mix.

The pellets were placed between steel split pins on a brass cylinder and ignited by an electric igniter enhanced with a quickmatch fixed with adhesive tape on top of the strands.

The burn rate and radiometric performance were determined in the range 3.0–5.1 µm with an IR radiometric system (RM 6600 and uncooled pyroelectric detector RkP 575 both from Laser Probe USA). The radiometer was calibrated with a black body (SR-32, CI Electro-Optical Systems, Haifa/Israel) at T = 1000 K.

Kuwahara had noted that the burn rate of MTV (65/30/5) increases upon addition of zirconium of

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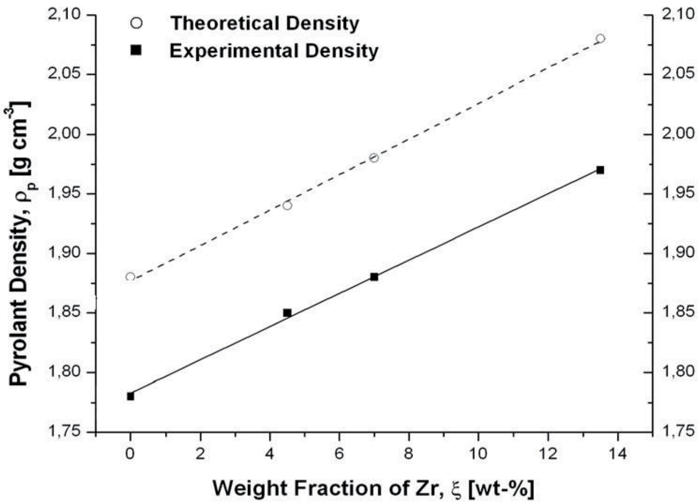

Figure 1. *Theoretical maximum density and experimental density of pyrolants.*

unspecified particle size. Now the present pyrolant was modified such that the MTV ratio was kept nearly constant with increasing zirconium content. Table 1 gives the actual stoichiometries. The experimental density of the pellets was ~ 94% theoretical maximum density (TMD) in all cases as can be seen from Figure 1.

Upon addition of zirconium the burn rate of the pyrolant increases to a range with a maximum at ~7% Zr, and thereafter it decreases again. This is in quite good accord with earlier findings.[7] However the burn rate increase is more pronounced than that reported by Kuwahara. This may be due to different particle size distributions. This work: MTZ (20/2/5.5) vs. Kuwahara: MTZ (60/600/?)[7].

The decrease in the burn rate at higher Zr contents is indicative of a minimum of two propagation mechanisms in the condensed phase. At first Zr imparts a higher volumetric exothermicity with PTFE as can be seen from the following equations:

$$Mg + 1/2n\ (C_2F_4)_n \rightarrow MgF_{2(s)} + C_{(gr)} \quad 18.57\ \text{kJ cm}^{-3} \qquad (1)$$

$$Zr + 1/n\ (C_2F_4)_n \rightarrow ZrF_{4(s)} + 2\ C_{(gr)} \quad 25.96\ \text{kJ cm}^{-3} \qquad (2)$$

This accounts for the observed increase in burn rate at lower zirconium percentages. The thermal diffusivity of zirconium, $\alpha(\text{Zr}) = 1.28 \times 10^{-5}$ (m^2 s^{-1}), is by a factor of 10 lower than the corresponding magnesium value, $\alpha(\text{Mg}) = 1.15 \times 10^{-4}$ (m^2 s^{-1}). As a consequence with increasing Zr content the overall diffusivity drops by ~5% and the burn rate slows down again. A similar effect has been measured by Kuo with boron modified fuel rich MTV (50/50) pyrolant.[8]

Although the burn rate increases upon addition of Zr it lowers the spectral efficiency as can be seen from the nearly exponential decrease in Figure 2.

At first hand this is quite unexpected as zirconium based flare compositions are known to have high

Table 1. *Composition details (wt%).*

	1	2	3	4
Magnesium	65	62	59	56.5
Polytetrafluoroethylene	30	29	27	26
Hexafluoropropene-*co*-vinylidene fluoride polymer	5	4.5	5	4.5
Zirconium	0	4.5	7	13.5

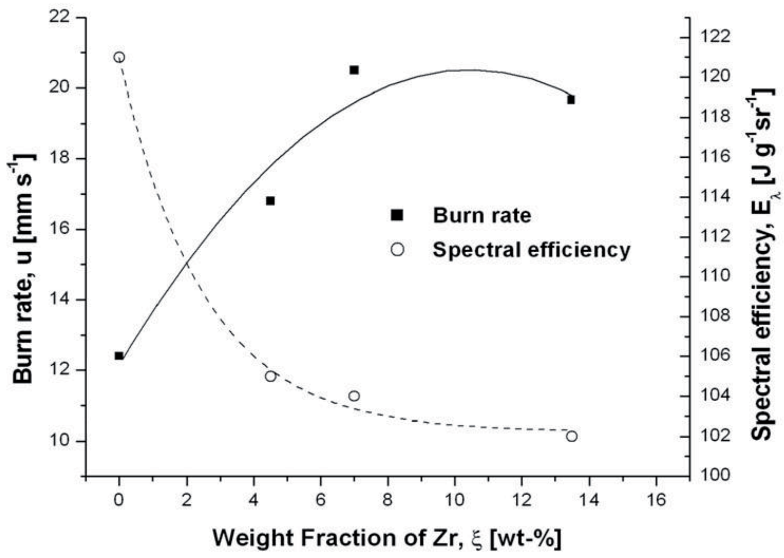

Figure 2. *Burn rate and spectral efficiency of pyrolants.*

radiant intensity.[9]

The fluorination of zirconium according to Glassman's criteria for metal combustion occurs entirely in the condensed phase.[10] Thus the aerobic diffusion flame responsible for the radiative heat feedback to the primary carbon rich zone cannot be altered by zirconium. As the magnesium content decreases linearly from 65 wt% to 56.6 wt% the decrease in performance can be explained.[3] Now the non-linear decrease of the spectral efficiency requires additional explanation. However this is not presently available.

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