

# Study on influence factors of the combustion temperature of MTV foil-type decoys and their interactions

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Received: July 23, 2018 Accepted: April 9, 2019

## Abstract

In order to study the influence factors of the combustion temperature of MTV foil-type infrared decoys and the interactions between these factors, the Minitab was used to design the four factors at two levels orthogonal experiment ( $2^4$ ), where the combustion temperature was recorded and tested using the SC7000 far-infrared thermal imager. The analysis results of the Minitab show that there are mainly five factors that influence the MTV combustion temperature, which are, in the order from the primary to the secondary the ratio of Mg/PTFE, the interaction between Viton content and dose, the interaction between the ratio of Mg/PTFE and dose, the dose and the interaction between the ratio of Mg/PTFE, Viton content and dose. The combustion temperature of MTV can be calculated using the following formula: Temperature =  $1390.32 + 77.82 \xi(\text{Mg})/\xi(\text{PTFE}) - 5.97 \xi(\text{Viton}) + 24.26m - 1.72 \xi(\text{Mg})/\xi(\text{PTFE}) * \xi(\text{Viton}) + 41.84 \xi(\text{Mg})/\xi(\text{PTFE}) * m + 65.07 \xi(\text{Viton}) * m - 22.49 \xi(\text{Mg})/\xi(\text{PTFE}) * \xi(\text{Viton}) * m$ . When the ratio of Mg/PTFE is 50/50 by weight, the Viton content is 10%, the dose is 5 g, and the maximum value of the combustion temperature is 1569.13 °C.

**Keywords:** pyrotechnics, MTV, combustion temperature, minitab, orthogonal experiment, mathematic model

## 1. Introduction

MTV (Mg/PTFE/Viton) pyrotechnic composition is widely used in decoy flares, countermeasure torches, base bleed units, tracer units, igniters, solid rocket propellants, RAM propellants, incendiary devices and signaling applications<sup>1)</sup>, because of its favorable properties such as high combustion temperature and stability, low moisture absorption and low cost<sup>1)-3)</sup>. So a lot of studies have been carried out by both Chinese and foreign scholars to identify the factors of the MTV characteristics.

Kuwahara and Koch found that, when  $\xi(\text{Mg}) = 30\%$ , the maximum flame temperature can reach 2998°C (0.1 MPa) and 3210°C (1 MPa). The combustion rate drops with the increase in the size of Mg, but rises with the increase in the size of PTFE. Furthermore, the combustion rate first rises and then drops with the increase of Mg content, and finally reaches the maximum when  $\xi(\text{Mg}) = 60\%$ <sup>4)-6)</sup>. Asuna acquired the

microcrystalline surface structure of Mg using PVD (physical vapor deposition) technique in the preparation of Mg/PTFE, which has a larger surface area, and better surface adsorption capacity and surface activity, thus contributing to the faster combustion rate<sup>7)</sup>.

Ming-hua and Qing-jie et al. studied the influence of charge density of infrared composition on the combustion and emission performance by calculating the combustion rate of MTV and found that the combustion rate drops with the increase in the size of Mg, and rises with the increase in the specific surface area<sup>8)</sup>. Jun studied the influences of the particle size and morphology of magnesium powder and the physical forms of MTV (such as the sheet-like and the column-like) on the performance of MTV infrared decoy<sup>9),10)</sup>, and the results showed that the combustion rate, combustion temperature, and far-infrared radiation intensity of the decoys are improved significantly with decreased particle size, and that the

**Table 1** Orthogonal experiment table.

StdOrder	RunOrder	CenterPt	Blocks	Mg/PTFE	Viton	Acetone [mL]	Dose [g]
9	1	1	1	40/60	8%	10	5
7	2	1	1	40/60	10%	14	3
6	3	1	1	50/50	8%	14	3
2	4	1	1	50/50	8%	10	3
11	5	1	1	40/60	10%	10	5
10	6	1	1	50/50	8%	10	5
8	7	1	1	50/50	10%	14	3
4	8	1	1	50/50	10%	10	3
5	9	1	1	40/60	8%	14	3
14	10	1	1	50/50	8%	14	5
16	11	1	1	50/50	10%	14	5
3	12	1	1	40/60	10%	10	3
1	13	1	1	40/60	8%	10	3
13	14	1	1	40/60	8%	14	5
12	15	1	1	50/50	10%	10	5
15	16	1	1	40/60	10%	14	5

**Table 2** The parameters of the reagents.

Reagent	Chemical formula	Purity or size	Manufacture
PTFE	(C <sub>2</sub> F <sub>4</sub> ) <sub>n</sub>	5 [μm]	Shanghai 3F New Materials Co., Ltd.
Magnesium	Mg	100–200 [mesh]	Shanghai Longxin Technology Co., Ltd.
Viton	C <sub>n</sub> H <sub>m</sub> F <sub>x</sub>	—	Chenguang Fluororubbers Co., Ltd.
Acetone	C <sub>3</sub> H <sub>6</sub> O	A.R, purity 99.5%	Shanghai Lingfeng Chemical Reagent Co., Ltd.

combustion rate and combustion temperature of flake-like magnesium powder are both higher than those of spherical powder because of the larger surface area. At the same diameter, sheet-like decoys exhibit higher combustion rate and combustion temperature. With the same physical form, a larger diameter leads to higher combustion rate, combustion temperature, and radiation brightness.

Most of the studies were carried out through changing one impact factor while setting the other parameters as constant, in order to study its influence on the combustion and radiation performance of MTV. However, there have been few studies investigating how different factors affect the combustion and radiation performance of MTV at the same time, or whether there is an interaction between different influence factors.

So, this paper designs an orthogonal experiment using Minitab software to study the influence factors of combustion temperature of MTV foil-type infrared decoy and the relationship between them.

## 2. Experiment design

The MTV foil-type infrared decoy was prepared by mixing Magnesium and PTFE at a certain ratio, dissolving the mixture in acetone with a certain content of Viton to make it into slurries with a certain concentration, pouring the slurries onto the metal foil and coating one side of the metal foil with the liquid slurries.

According to the preparation process of the MTV foil-type infrared decoy, the influence factors of combustion temperature of MTV may consist of the ratio of Mg/

PTFE, Viton content, amount of acetone and the dose of the composition. To study the influence on the combustion temperature of MTV and the interaction between the factors, a four factors at two levels orthogonal experiment (2<sup>4</sup>) was designed using Minitab, in which the four factors are the ratio of Mg/PTFE (40/60 and 50/50 by weight), Viton content (8% and 10%), amount of acetone (10 mL and 14 mL) and dose (3 g and 5 g). The orthogonal experiment table randomly generated using Minitab is shown in Table 1.

## 3. Experiments

### 3.1 Materials

Purities, or particle sizes, and manufactures of the used reagents are summarized in Table 2.

### 3.2 Sample Preparation

Different samples were prepared, as shown in Table 1. Taking the first row (the StdOrder is 9, RunOrder is 1) in Table 1 as example, the samples were prepared through mixing 2 g PTFE and 3 g Mg uniformly, dissolving the mixture in 10 ml acetone which contains 0.4 g Viton, dumping the resulting slurries on one side of the metal foil (30 μm thick and 6 cm × 6 cm in size) equably, evenly dispersing the liquid slurries on the foil surface, drying the slurry coating at 25°C for 5 h, dividing the foil into four parts (3 cm × 3 cm each) and finally coating 0.1 g ignition on the center of the small foil. The preparation process of the sample is shown in Figure 1, and Figure 2 shows the schematic diagram of foil-type decoy.

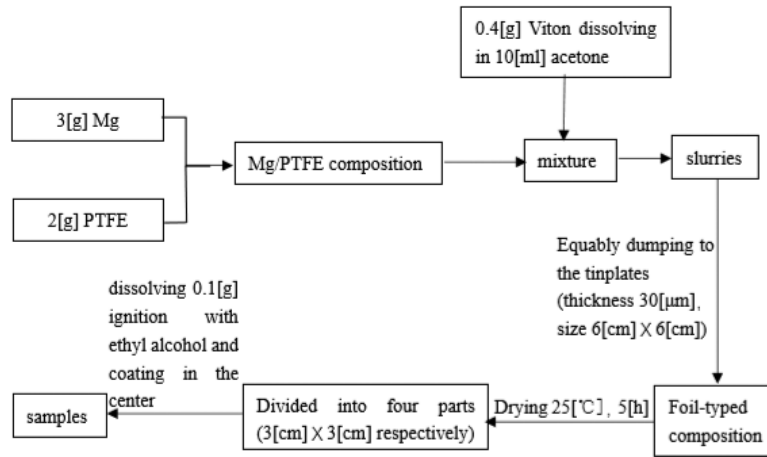


Figure 1 The preparation process of the samples.



Figure 2 The schematic diagram of the samples (about 1 [mm] thick).

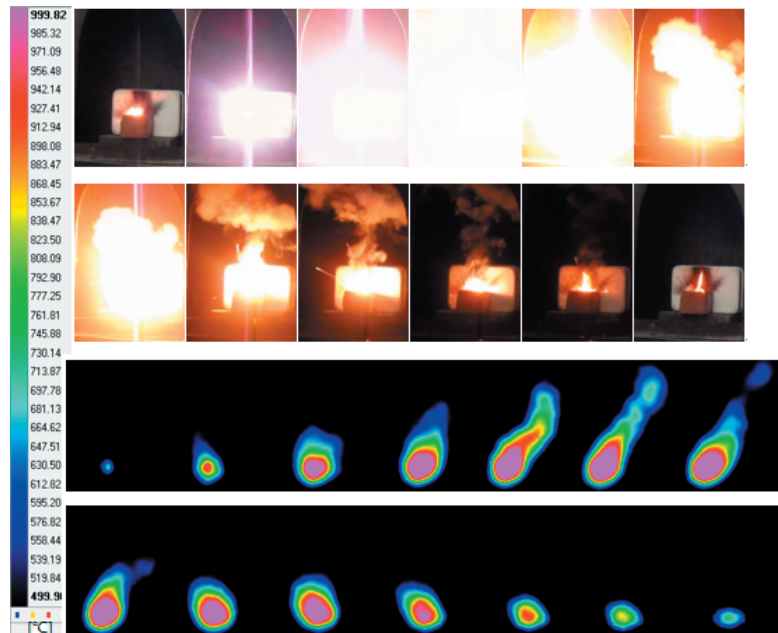


Figure 3 The combustion process (visible and infrared views respectively).

### 3.3 Experimental conditions

The combustion process was recorded using the high-speed camera (HG-100K, Redlake, US) with an exposure time of 650 $\mu$ s and a sampling frequency of 1000Hz, and data were collected using Motion Central control and image acquisition workstation.

The combustion temperature was tested using a far-infrared thermal imager (SC7000, Flir Systems, US) working at a test distance of 2m and with a spectral response range of 7.7–9.3  $\mu$ m.

All samples were placed vertically in front of the instruments with an interval of 2m, and ignited using nitro-cotton strips. In order to reduce testing errors, each composition was tested in four replicates, the mean result of which was adopted as valid data.

## 4. Results and discussion

### 4.1 Testing phenomenon and results

The combustion process was recorded using the high-speed camera and the combustion temperature was tested using the SC7000 far-infrared thermal imager. Figure 3

shows the combustion process of the sample in the first row in Table 1 (the StdOrder is 9, RunOrder is 1) in both visible and infrared views.

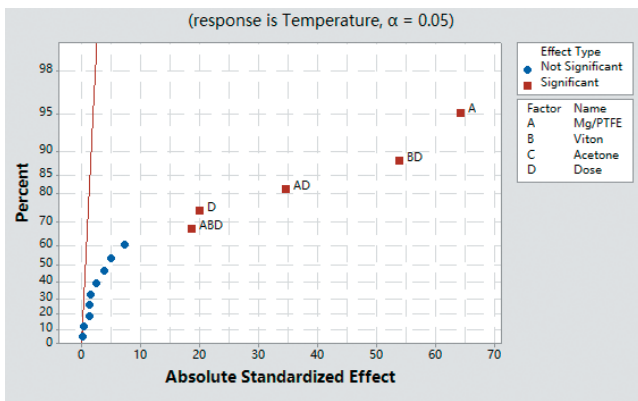
The thermograph was analyzed using the built-in software Altair of SC7000 far-infrared thermal imager by selecting the combustion area with a temperature of above 500  $^{\circ}$ C, of which the average combustion temperature could be achieved automatically. The combustion temperature in every second could be achieved by analyzing all the IR thermograph during the combustion process. And the average combustion temperature of the sample could be obtained by calculating the arithmetic mean of all combustion temperatures in every second. Table 3 shows the combustion temperature of all samples.

### 4.2 Analysis of DOE

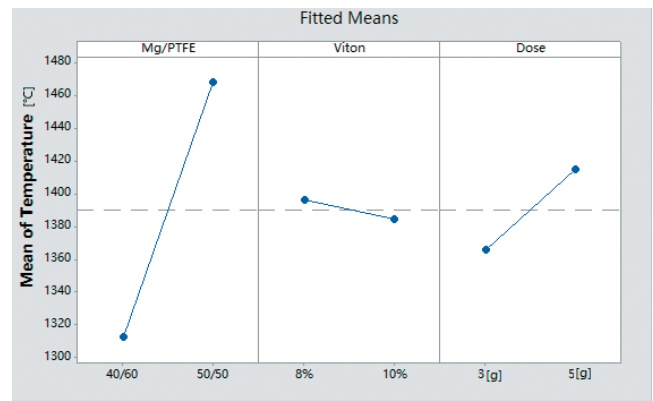
Minitab was used to perform the DOE analysis of the influence factors and the interactions between them. The half normal plot of the standardized effects is shown in Figure 4, The percentage of vertical axis in Figure 4 is the

**Table 3** The combustion temperature results of all samples.

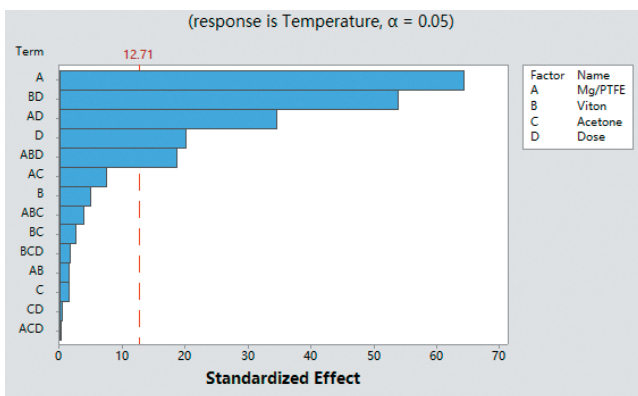
StdOrder	RunOrder	Mg/PTFE	Viton	Acetone [ml]	Dose [g]	Temperature [°C]
9	1	40/60	8%	10	5	1201.79
7	2	40/60	10%	14	3	1251.11
6	3	50/50	8%	14	3	1448.78
2	4	50/50	8%	10	3	1455.85
11	5	40/60	10%	10	5	1366.53
10	6	50/50	8%	10	5	1495.12
8	7	50/50	10%	14	3	1339.34
4	8	50/50	10%	10	3	1364.21
5	9	40/60	8%	14	3	1429.89
14	10	50/50	8%	14	5	1503.59
16	11	50/50	10%	14	5	1551.82
3	12	40/60	10%	10	3	1225.42
1	13	40/60	8%	10	3	1413.92
13	14	40/60	8%	14	5	1221.41
12	15	50/50	10%	10	5	1586.44
15	16	40/60	10%	14	5	1389.91



**Figure 4** Half normal plot of the standardized effects.



**Figure 6** Main effects plot for temperature.



**Figure 5** The influence degree of various factors on combustion temperature.

influence degree of each factor or interaction factor on combustion temperature obtained by Minitab analysis, and the Pareto chart of the standardized effects is shown in Figure 5.

The Figure 4 and Figure 5 show that there are five main influence factors of the MTV combustion temperature, which are, in the order from the primary to the secondary, the ratio of Mg/PTFE, the interaction between Viton content and dose, the interaction between

the ratio of Mg/PTFE and dose, the dose and the interaction between the ratio of Mg/PTFE, Viton content and Dose. Figure 5 shows that 12.71 is the standardized minimum value that Minitab can obtain Standardized Effect of factors that have a significant impact on the combustion temperature of foil-type decoys. The specific results are shown as Table 4.

As mentioned above,  $P$  is the probability value, which signifies a probability when an original hypothesis is true. According to the test method of statistics significance, a result is significant when  $P < 0.05$ , and it is non-significant or of no difference when  $P > 0.05$ . As shown in the results, the  $P$  value of the ratio of Mg/PTFE is  $0.01 < 0.05$ , the Dose is  $0.032 < 0.05$ , the interaction between the ratio of Mg/PTFE and Dose is  $0.018 < 0.05$ , the interaction between Viton content and Dose is  $0.012 < 0.05$  and the interaction between the ratio of Mg/PTFE, Viton content and Dose is  $0.034 < 0.05$ , indicating that all the five factors and their interactions are significant. In addition, the  $P$  value of other factors and interactions are all above 0.05, which means that they are not significant or make no difference.

So, the main factors that influence the MTV combustion temperature include the ratio of Mg/PTFE, the Dose, the

**Table 4** The DOE analysis of the influence factors and the interactions.

Factorial Regression: Temperature versus Mg/PTFE, Viton, Acetone, Dose						
Analysis of Variance						
Source	DF	Adj SS	Adj MS	F-Value	P-Value	
Model	14	212662	15190.1	650.46	0.031	
Linear	4	106931	26732.8	1144.73	0.022	
Mg/PTFE	1	96903	96903.0	4149.48	0.010	
Viton	1	571	570.9	24.44	0.127	
Acetone	1	44	44.1	1.89	0.400	
Dose	1	9413	9413.4	403.09	0.032	
2-Way Interactions	6	97228	16204.6	693.90	0.029	
Mg/PTFE*Viton	1	47	47.2	2.02	0.390	
Mg/PTFE*Acetone	1	1274	1273.6	54.54	0.086	
Mg/PTFE*Dose	1	28014	28013.6	1199.57	0.018	
Viton*Acetone	1	140	140.5	6.02	0.246	
Viton*Dose	1	67750	67749.6	2901.10	0.012	
Acetone*Dose	1	3	3.2	0.14	0.775	
3-Way Interactions	4	8503	2125.8	91.03	0.078	
Mg/PTFE*Viton*Acetone	1	346	345.7	14.80	0.162	
Mg/PTFE*Viton*Dose	1	8095	8095.1	346.64	0.034	
Mg/PTFE*Acetone*Dose	1	1	1.2	0.05	0.856	
Viton*Acetone*Dose	1	61	61.0	2.61	0.353	
Error	1	23	23.4			
Total	15	212685				
Mg/PTFE*Acetone*Dose	0.56	0.28	1.21	0.23	0.856	1.00
Viton*Acetone*Dose	-3.91	-1.95	1.21	-1.62	0.353	1.00
Regression Equation in Uncoded Units						
Temperature = 1390.32 + 77.82 $\xi(\text{Mg}) / \xi(\text{PTFE}) - 5.97 \xi(\text{Viton}) + 1.66 \xi(\text{Acetone}) + 24.26 m$						
- 1.72 $\xi(\text{Mg}) / \xi(\text{PTFE}) * \xi(\text{Viton}) - 8.92 \xi(\text{Mg}) / \xi(\text{PTFE}) * \xi(\text{Acetone})$						
+ 41.84 $\xi(\text{Mg}) / \xi(\text{PTFE}) * m - 2.96 \xi(\text{Viton}) * \xi(\text{Acetone}) + 65.07 \xi(\text{Viton}) * m$						
+ 0.45 $\xi(\text{Acetone}) * m - 4.65 \xi(\text{Mg}) / \xi(\text{PTFE}) * \xi(\text{Viton}) * \xi(\text{Acetone})$						
- 22.49 $\xi(\text{Mg}) / \xi(\text{PTFE}) * \xi(\text{Viton}) * m + 0.28 \xi(\text{Mg}) / \xi(\text{PTFE}) * \xi(\text{Acetone}) * m$						
- 1.95 $\xi(\text{Viton}) * \xi(\text{Acetone}) * m$						
In this mathematical formulas $\xi(\text{Mg}) / \xi(\text{PTFE})$ is the ratio of Mg / PTFE, $\xi(\text{Viton})$ is Viton content, $\xi(\text{Acetone})$ is the amount of acetone, and m is the dose.						
Model Summary						
S	R-sq	R-sq (adj)	R-sq (pred)			
4.8325	99.99%	99.84%	97.19%			

interaction between the ratio of Mg/PTFE and Dose, the interaction between Viton content and Dose and the interaction between the ratio of Mg/PTFE, Viton content and Dose.

### 4.3 Analysis of main effect

It is known from the above results that the acetone content has little influence on the MTV combustion temperature, because the acetone will volatilize during the drying process. For the sake of analysis, the influence of acetone was ignored, and the main effects plot for combustion temperature is shown in Figure 6.

The Figure 6 shows that the MTV combustion temperature rises with the increase in the Mg content, when only considering the influence of the ratio of Mg/PTFE on MTV combustion temperature.

This is because, on one hand, every 1.32 g PTFE can release 1 g fluorine, and combustion with 1 g fluorine needs

0.64 g Mg<sup>11)</sup>, suggesting that the ratio of Mg/PTFE is 33/67 by weight when there is zero oxygen balance. With the increase in Mg content, there will be more Mg left after the oxidation-reduction reaction between Mg and PTFE, which will add to the reaction between the surplus Mg and O<sub>2</sub> in the air, thus increasing the heat release of the reaction.

On the other hand, the formula for the temperature coefficient is as follows<sup>12)</sup>:

$$\alpha = \frac{\lambda}{\rho C_p} \quad (1)$$

where  $\lambda$  is thermal conductivity,  $\rho$  is density and  $C_p$  is the specific heat at constant pressure. The  $\lambda$  and  $C_p$  of MTV are calculated as<sup>12)</sup>:

$$\lambda = \frac{\lambda_{\text{Mg}} \cdot \lambda_{\text{PTFE}}}{\xi_{\text{Mg}} \cdot \lambda_{\text{PTFE}} \cdot \xi_{\text{PTFE}} \cdot \lambda_{\text{Mg}}} \quad (2)$$



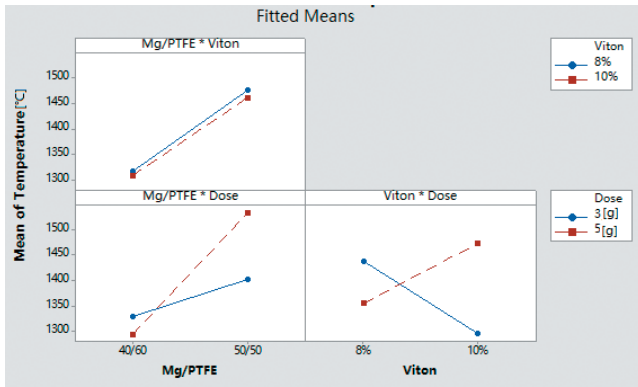


Figure 7 Interaction plot for temperature.

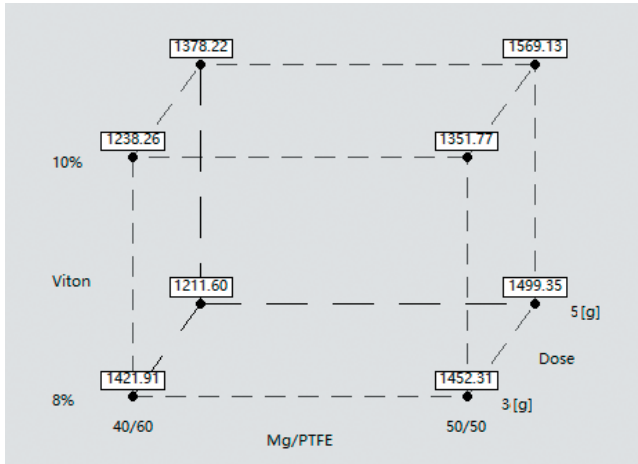


Figure 8 Cube plot for temperature.

$$C_p = \xi_{Mg} \cdot C_{pMg} \cdot \xi_{PTFE} \cdot C_p \quad (3)$$

where  $\lambda_{Mg} = 156 \text{ W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$ ,  $\lambda_{PTFE} = 0.24 \text{ W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$ ,  $C_{pMg} = 0.293 \text{ kJ} \cdot \text{kg}^{-1} \cdot \text{K}^{-1}$  and  $C_{pPTFE} = 0.96 \text{ kJ} \cdot \text{kg}^{-1} \cdot \text{K}^{-1}$ . When the ratio of Mg/PTFE by weight is 40/60,  $\lambda_1 = 4.0 \times 10^{-3} \text{ W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$  and  $C_{p1} = 69.32 \text{ kJ} \cdot \text{kg}^{-1} \cdot \text{K}^{-1}$ . When the ratio is 50/50,  $\lambda_1 = 4.8 \times 10^{-3} \text{ W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$ , and  $C_{p1} = 62.65 \text{ kJ} \cdot \text{kg}^{-1} \cdot \text{K}^{-1}$ . It means that  $C_p$  decreases with the increase in  $\lambda$ . According to Equation (1),  $\alpha$  rises with the increase in Mg content, which means that the unreacted region reaches the reaction temperature faster and accelerates the reaction rate. Therefore, concentration of the reaction energy leads to the increase of MTV combustion temperature.

The MTV combustion temperature drops with the increases in Viton content, when only considering the influence of this factor. This is because Viton impedes the contact and reaction between Mg and PTFE, which lengthens the reaction time and facilitates the dispersion of the reaction heat, thus decreasing the MTV combustion temperature.

The MTV combustion temperature rises with the increases in dose, when only considering the influence of this factor. The reason is that, with the increase in Dose, the combustion reaction releases more heat, increasing the combustion temperature.

Among the three figures in Figure 6, the slope of Mg/PTFE is the steepest, respectively that the influence of Mg/PTFE on MTV combustion temperature is the most

significant, followed by those of Dose and Viton content.

#### 4.4 Analysis of interaction

The result of Minitab analysis on the interactions between the influence factors of the MTV combustion temperature is shown in Figure 7.

The Figure 7 shows that the lines of the ratio of Mg/PTFE and Viton content are parallel, suggesting that there is no interaction between the the two factors.

There exists a cross point between both the lines of the ratio of Mg/PTFE and Dose, and those of Viton content and dose, which means that there are interactions between ratio of Mg/PTFE and Dose and between Viton content and Dose. In addition, the angle between the line of Viton content and that of Dose is bigger, suggesting that, compared with the interaction between the ratio of Mg/PTFE and Dose, the interaction between Viton content and Dose is more significant.

The cube plot for MTV combustion temperature acquired through analyzing the common influence of the ratio of Mg/PTFE, Viton content and Dose using Minitab is shown in Figure 8.

When ignoring the influence of acetone content, the MTV combustion temperature can reach 1569.13 °C in these experiments, with the composition of Mg/PTFE by weight, Viton content and the Dose being, respectively, 50 /50, 8% and 5 g. The maximum combustion temperature is 29.5% higher than the minimum combustion temperature (1211.60°C).

#### 4.5 Mathematical model optimization

When considering all the influence factors and interactions, the mathematic model of the MTV combustion temperature is:

$$\begin{aligned} \text{Temperature} = & 1390.32 + 77.82 \xi(\text{Mg}) / \xi(\text{PTFE}) - 5.97 \\ & \xi(\text{Viton}) + 1.66 \xi(\text{Acetone}) + 24.26 m - 1.72 \xi(\text{Mg}) / \xi \\ & (\text{PTFE}) * \xi(\text{Viton}) - 8.92 \xi(\text{Mg}) / \xi(\text{PTFE}) * \xi(\text{Acetone}) + \\ & 41.84 \xi(\text{Mg}) / \xi(\text{PTFE}) * m - 2.96 \xi(\text{Viton}) * \xi(\text{Acetone}) + \\ & 65.07 \xi(\text{Viton}) * m + 0.45 \xi(\text{Acetone}) * m - 4.65 \xi(\text{Mg}) / \xi \\ & (\text{PTFE}) * \xi(\text{Viton}) * \xi(\text{Acetone}) - 22.49 \xi(\text{Mg}) / \xi(\text{PTFE}) * \xi \\ & (\text{Viton}) * m + 0.28 \xi(\text{Mg}) / \xi(\text{PTFE}) * \xi(\text{Acetone}) * m - \\ & 1.95 \xi(\text{Viton}) * \xi(\text{Acetone}) * m \end{aligned} \quad (4)$$

To optimize the mathematic model, the influence factors and interactions with a  $P$  value above 0.05 are ignored, reserving those with a  $P$  value below 0.05, including Mg/PTFE, Viton, Dose, Mg/PTFE\*Dose, Viton\*Dose and Mg/PTFE\*Viton\*Dose. In order to analyze Mg/PTFE\*Viton\*Dose, it is necessary to consider Mg/PTFE\*Viton. These seven influence factors and interactions on MTV combustion temperature were analyzed using Minitab, of which the specific results are shown as Table 5, and the residual plots for temperature is shown in Figure 9.

From the normal probability plot in the first diagram of Figure 9, Residual shows a normal distribution. The second diagram versus fits shows that the distribution is point-symmetric, without bell-shaped and u-shaped, indicating a good fit. The fourth diagram versus order

**Table 5** The influence of Mg / PTFE, Viton, Dose, Mg / PTFE\*Dose, Viton\*Dose and Mg / PTFE\*Viton\*Dose on MTV combustion temperature

Analysis of Variance						
Source	DF	Adj SS	Adj MS	F-Value	P-Value	
Model	7	210793	30113.2	127.28	0.000	
Linear	3	106887	35629.1	150.60	0.000	
Mg/PTFE	1	96903	96903.0	409.59	0.000	
Viton	1	571	570.9	2.41	0.159	
Dose	1	9413	9413.4	39.79	0.000	
2-Way Interactions	3	95810	31936.8	134.99	0.000	
Mg/PTFE*Viton	1	47	47.2	0.20	0.667	
Mg/PTFE*Dose	1	28014	28013.6	118.41	0.000	
Viton*Dose	1	67750	67749.6	286.36	0.000	
3-Way Interactions	1	8095	8095.1	34.22	0.000	
Mg/PTFE*Viton*Dose	1	8095	8095.1	34.22	0.000	
Error	8	1893	236.6			
Total	15	212685				
Model Summary						
S	R-sq	R-sq (adj)	R-sq (pred)			
15.3813	99.11%	98.33%	96.44%			
Coded Coefficients						
Term	Effect	Coef	SE Coef	Stand Error of Coef	T-Value	P-Value
Constant		1390.32	3.85	361.56	0.000	
Mg/PTFE		155.65	77.82	3.85	20.24	0.000
Viton		-11.95	-5.97	3.85	-1.55	0.159
Dose		48.51	24.26	3.85	6.31	0.000
Mg/PTFE*Viton		-3.44	-1.72	3.85	-0.45	0.667
Mg/PTFE*Dose		83.69	41.84	3.85	10.88	0.000
Viton*Dose		130.14	65.07	3.85	16.92	0.000
Mg/PTFE*Viton*Dose		-44.99	-22.49	3.85	-5.85	0.000
Regression Equation in Uncoded Units						
Temperature = 1390.32 + 77.82 $\xi$ (Mg) / $\xi$ (PTFE) - 5.97 $\xi$ (Viton) + 24.26m - 1.72 $\xi$ (Mg) / $\xi$ (PTFE) * $\xi$ (Viton) + 41.84 $\xi$ (Mg) / $\xi$ (PTFE)*m + 65.07 $\xi$ (Viton)*m - 22.49 $\xi$ (Mg) / $\xi$ (PTFE) * $\xi$ (Viton)*m.						

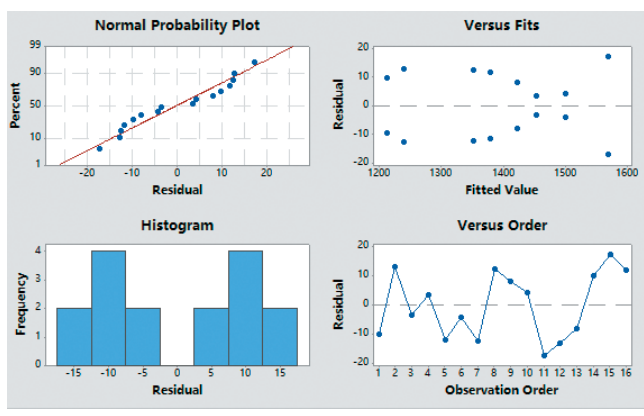


Figure 9 Residual plots for temperature.

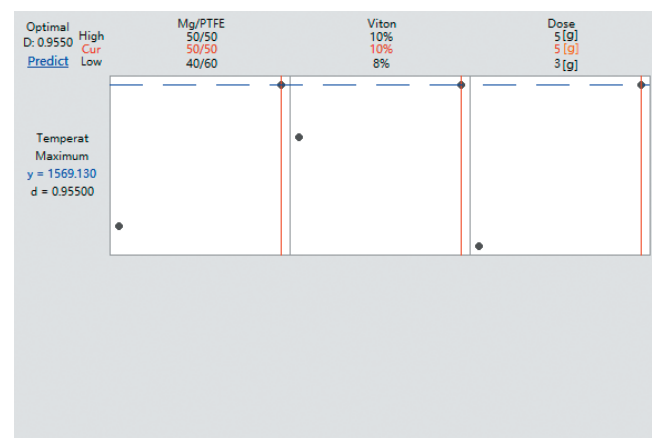


Figure 10 The results of response optimization.

shows that there is no out-of-control. All results showed normal residuals. The results show that the mathematic model is reasonable, and that the MTV combustion temperature fits the following formula:

$$\text{Temperature} = 1390.32 + 77.82 \xi(\text{Mg}) / \xi(\text{PTFE}) - 5.97 \xi(\text{Viton}) + 24.26m - 1.72 \xi(\text{Mg}) / \xi(\text{PTFE}) * \xi(\text{Viton}) + 41.84 \xi(\text{Mg}) / \xi(\text{PTFE}) * m + 65.07 \xi(\text{Viton}) * m - 22.49 \xi(\text{Mg}) / \xi(\text{PTFE}) * \xi(\text{Viton}) * m \quad (5)$$

#### 4.6 Formula of the maximum combustion temperature

In order to obtain the formula of the maximum combustion temperature, factor optimization is conducted by using Minitab and Temperature was set to maximize which is shown in Figure 10.

According to Figure 10, the highest MTV combustion temperature in formula (8) is 1569.13 °C, when the ratio of Mg/PTFE by weight is 50/50, the Viton content is 10%, and the Dose is 5 g. The composite desirability of the experiment results – 1586.44 °C (when the acetone content is 10 ml) and 1551.82 °C (when the acetone content is 14 ml) – reaches 0.954998.

#### 5. Conclusion

(1) There are five main factors which influence the MTV combustion temperature, which are, in the order from the primary to the secondary, the ratio of Mg/PTFE, the interaction between Viton content and Dose, the interaction between the ratio of Mg/PTFE and Dose, the Dose and the interaction between the ratio of Mg/PTFE, Viton content and Dose.

(2) Acetone content has a negligible influence on the MTV combustion temperature because of the volatilization of acetone.

(3) When just considering one influence factor, the MTV combustion temperature rises with the increases in Mg content in Mg/PTFE and Dose, and drops with the increases in Viton content. The influence of the ratio of Mg/PTFE is the most significant, followed by the Dose, while that of Viton content is the least.

(4) There is no interaction between the ratio of Mg/PTFE and Viton content. Compared with the interaction between the ratio of Mg/PTFE and Dose, that between

Viton content and Dose is more significant.

(5) The formula of the MTV combustion temperature is:  $\text{Temperature} = 1390.32 + 77.82 \xi(\text{Mg})/\xi(\text{PTFE}) - 5.97 \xi(\text{Viton}) + 24.26 m - 1.72 \xi(\text{Mg})/\xi(\text{PTFE}) * \xi(\text{Viton}) + 41.84 \xi(\text{Mg})/\xi(\text{PTFE}) * m + 65.07 \xi(\text{Viton}) * m - 22.49 \xi(\text{Mg})/\xi(\text{PTFE}) * \xi(\text{Viton}) * m$ . The MTV combustion temperature reaches the maximum 1569.13 °C when the ratio of Mg/PTFE by weight is 50/50, the Viton content is 10%, and the Dose is 5 g.

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