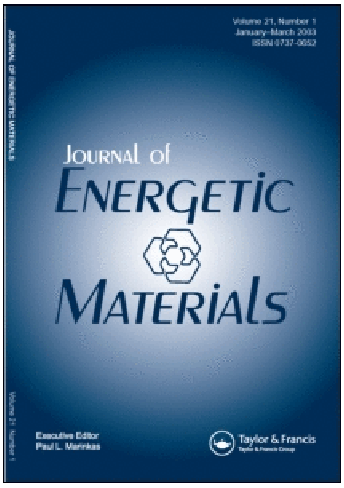


Journal of Energetic Materials
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713770432

The Effect of Ambient Temperature and Boron Content on the Burning Rate of the B/Pb_3O_4 Delay Compositions

Yanchun Li[a]; Yi Cheng[a]; Yun-Long Hui[a]; Shi Yan[a]
[a] School of Chemical Engineering, Nanjing University of Science and Technology, Nanjing, P.R. China

Online publication date: 06 April 2010

To cite this Article Li, Yanchun , Cheng, Yi , Hui, Yun-Long and Yan, Shi(2010) 'The Effect of Ambient Temperature and Boron Content on the Burning Rate of the B/Pb_3O_4 Delay Compositions', Journal of Energetic Materials, 28: 2, 77 — 84
To link to this Article: DOI: 10.1080/07370650903193299
URL: http://dx.doi.org/10.1080/07370650903193299

Journal of Energetic Materials, 28: 77–84, 2010

ISSN: 0737-0652 print/1545-8822 online
DOI: 10.1080/07370650903193299

The Effect of Ambient Temperature and Boron Content on the Burning Rate of the B/Pb_3O_4 Delay Compositions

YANCHUN LI, YI CHENG,
YUN-LONG HUI, and SHI YAN

School of Chemical Engineering, Nanjing University of Science and Technology, Nanjing, P.R. China

The burning rates of B/Pb_3O_4 delay compositions were investigated. Boron content was varied from 1 to 16% and the ambient temperature from −50°C up to 70°C. The measured burn rates increased as both parameters were increased and ranged from 1.28 to 3.12 cm/s. The data were correlated using an empirical model.

Keywords: B/Pb_3O_4 delay composition, burning rate, burning rate model, delay composition

Introduction

Modern pyrotechnic applications demand delay compositions that ignite reliably and burn with precise and consistent rates [1–5]. Boron- [6–14] and lead-containing [1,13–16] delay compositions attracted interest for detonator applications due to their excellent performance. Jakubko [1,16] and Jakubko and Cernoskova [15] performed thermal analysis and investigated the effect of pressure and temperature on the burning rate of

Address correspondence to Yi Cheng, School of Chemical Engineering, Nanjing University of Science and Technology, Nanjing 210094, P.R. China. E-mail: chengyi20@yahoo.com.cn

the silicon–red lead system. Holloway et al. [12] studied boron–lead monoxide formulations. B/Pb_3O_4 mixtures feature good reproducibility and a low critical initiation current [11]. Yunan Malak [13] used boron and red lead in nonelectric detonators without a percussion element. Whelan et al. [14] studied the ignition transfer characteristics of ternary mixtures of boron, red lead oxide and chromic oxide. Whelan et al. [6] also studied the thermal decomposition of BLC 190 (boron:red lead, 10:90). They found that the reaction is gasless and forms lead borate rather than boric oxide:

$$12\,B + Pb_3O_4 \rightarrow 3PbO \cdot 2B_2O_3$$

The above reaction scheme implies that stoichiometry corresponds to a boron content of 15.9 wt%. This investigation considered the effect of boron content and ambient temperature on the burn rate of fuel-lean compositions.

Experimental

Materials and Mixing

The boron powder was 95% pure and had a particle size less than 11 μm. The Pb_3O_4 powder was 95% pure and had a particle size less than 5 μm. The compositions were mixed by a wet ball-milling method using distilled water and steel balls. The wet ball-milling had a dual purpose. It facilitated mixing and may have caused further attrition of the particles. After mixing, the water was removed by drying the compositions in an oil-heated oven. After that, the compositions were granulated using a 30-mesh granulator. Mixtures were prepared with compositions ranging from 1 mass % boron to 16 mass % in 3% steps.

Loading Procedures

The delay compositions were pressed in a T-shaped iron tube (inner diameter 3.5 mm, outer diameter 6.5 mm, length 17 mm; see Fig.1). The loading procedure comprised the following steps: first, a load of 60 mg of a Si/Pb_3O_4 ignition composition

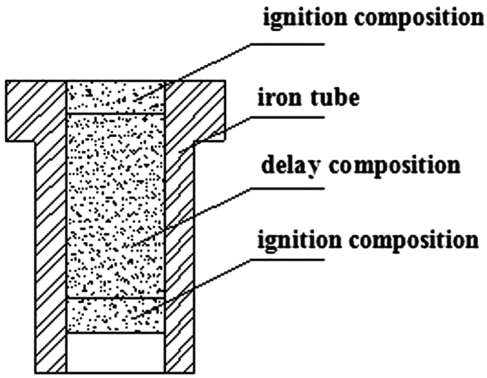
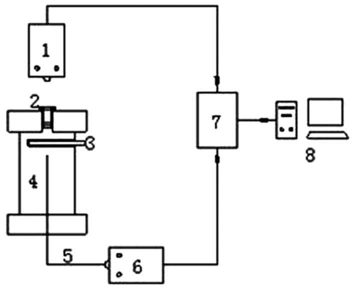


Figure 1. The T-shaped iron tube.

was filled into the tube and manually pressed with a punch. Next the B/Pb_3O_4 mixtures were loaded in two 150-mg increments and pressed. The filling was completed by adding another 60 mg Si/Pb_3O_4 as ignition increment. The delay compositions were consolidated using a pressure of 312.5 MPa using a C-frame hydraulic press.

Measuring Device

The measuring principle is illustrated in Fig. 2. The T-shaped iron tube was placed in the thermal insulation device. It was heated in an oil-heated oven or cooled in a low-temperature refrigerator. The device was kept at −50, −10, 25, 50 and 70°C for 30 min before testing. The compositions were ignited via electric fuses. The delay time was measured using a light-sensing method utilizing two photoelectric sensors. The first photo sensor was triggered on ignition. The start time was recorded by a Transient Test Card (PCI50612, Tuopu Measurement and Control Technology Co., Ltd., Chengdu, China). The end of the combustion event in the column was recorded by the second sensor. The burning rate was calculated as the length of the B/Pb_3O_4 column divided by the recorded burning time. The reaction time of the fuse heads used was not taken into account because of their shortness and good reproducibility.



1 photo-electricity transform equipment1; 2 iron tube; 3 glass sheet
4 thermal insulation device; 5 optical fiber;
6 photo-electricity transform equipment2; 7 Transient Test card; 8 computer

Figure 2. Measuring device of burning time.

However, corrections were made for the Si/Pb_3O_4 ignition compositions using their average reaction times and lengths.

Results and Discussion

The burning rates of B/Pb_3O_4 delay compositions were measured at temperatures of −50, −10, 25, 50, and 70°C. Each data point listed in Table 1 represents an average of five measurements. Figures 3 and 4 show that B/Pb_3O_4 mixtures burn faster as the boron content or ambient temperature increases. The temperature dependence of the burning rate is approximately linear for all mixtures. Note that the slopes of these lines increases with the boron content of the mixtures. The present empirical data are adequately correlated by the following empirical model:

$$y = (A + BT)\,\ell n\,(1 + Cx^{0.25}) \qquad (1)$$

where y is the burn rate in cm/s; T is the absolute temperature in K, and x is the boron concentration in mass %. The adjustable parameters A, B, and C were determined by a least squares fit to the entire data set. They take the following values: $A = 69.11$, $B = 0.1087$, and $C = 0.01433$. The predictions of

Table 1
Burning rate (cm/s) and the standard deviations of B/Pb_3O_4

Temperature	1%	4%	7%	10%	13%	16%
−50°C	1.28/0.008	1.85/0.07	2.13/0.066	2.46/0.037	2.48/0.026	2.67/0.071
−10°C	1.29/0.04	2.01/0.067	2.15/0.045	2.51/0.038	2.51/0.102	2.81/0.089
25°C	1.33/0.014	2.14/0.05	2.19/0.062	2.59/0.124	2.63/0.067	2.89/0.07
50°C	1.37/0.014	2.18/0.059	2.26/0.07	2.60/0.106	2.67/0.032	3.11/0.102
70°C	1.37/0.023	2.20/0.12	2.32/0.054	2.70/0.058	2.88/0.02	3.12/0.085

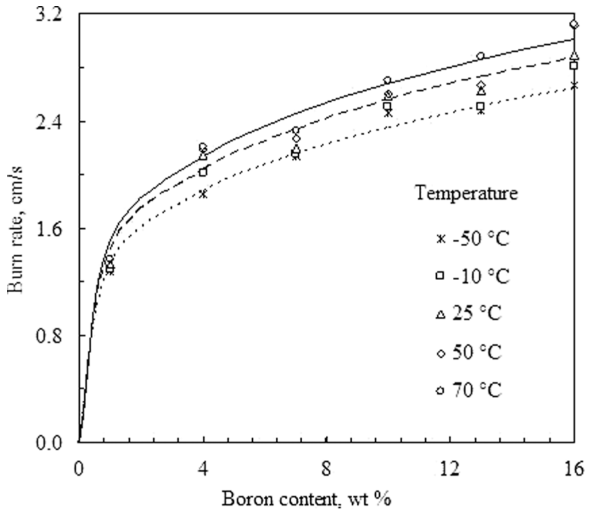


Figure 3. Temperature dependency of the burn rate and the simulated lines for the B/Pb_3O_4 mixtures.

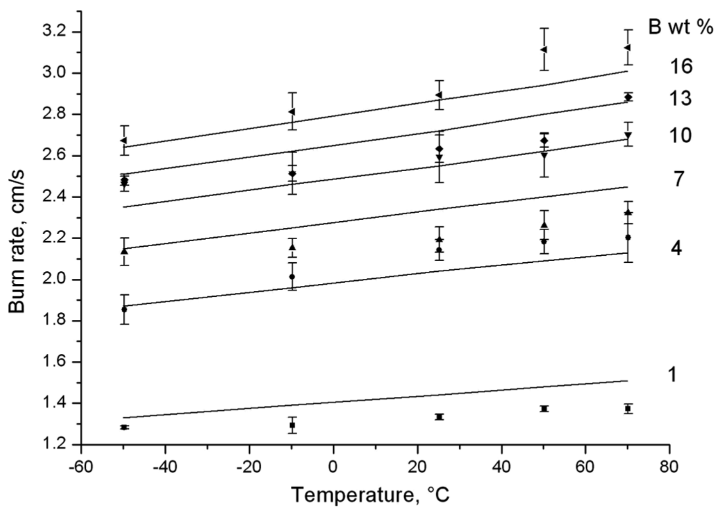


Figure 4. Boron content dependency of the burn rate and the simulated lines for the B/Pb_3O_4 mixtures.

Eq. (1), with these parameter values, are shown as solid lines in Figs. 3 and 4.

Conclusions

The effect of ambient temperature and boron content on the burn rate of the pyrotechnic delay system B/Pb_3O_4 was studied. For fixed composition the burn rate increased linearly with temperature. The effect of composition was more pronounced that that of temperature. The effect of composition on burn rate showed a logarithmic dependence.

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