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Effect of magnesium on the burning characteristics of boron particles

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ABSTRACT

Boron is an attractive fuel for propellants and explosives because of its high energy density. However, boron particles are difficult to combust because of inhibiting oxide layers that cover the particles. The use of magnesium as additives has been shown to promote boron oxidation. In this study, laser ignition facility and thermobalance were used to investigate the effect of magnesium on the burning characteristics of boron particles. The influences of magnesium addition on sample combustion flame, boron ignition delay time, boron combustion efficiency and initial temperature of boron oxidation. Results show that all Mg/B samples exhibit the same type of flame structure, i.e., a bright plume surrounded by green radiation which is interpreted as BO_2 emission. The combustion flame intensity of a sample increases with the increasing magnesium content of boron particles. An increase in magnesium content results in a decrease and a subsequent increase in boron ignition delay time. $(Mg/B)_{0.2}$ has a minimum ignition delay time of ~48 ms. Boron combustion efficiency increases with increasing magnesium addition. $(Mg/B)_{0.5}$ shows a maximum boron combustion efficiency of ~64.2%. Magnesium addition decreases the initial temperature of boron oxidation.

1. Introduction

Elemental boron has long been of interest as a fuel for propellants and explosives [1]. Among all chemical elements, boron has the highest volumetric heat of combustion (140 kJ/cm^3) and the third highest gravimetric heat of combustion (59 kJ/cm^3) after H_2 and Be [2]. Although boron exhibits exceptional performance characteristics, its potential as fuel or a fuel additive has not yet been realized thoroughly, partly because of the difficulty in achieving complete boron combustion [3]. Most boron particles contain an oxide layer on the outside surface [4]. Boron ignition is hindered by this protective oxide layer, which liquefies at relatively low temperatures (450 °C at 1 atm) and slows oxidizer attacks on the underlying boron material [5]. Boron also has a high vaporization temperature (3727 °C at 1 atm). The melting point of the oxide layer is considerably lower than the melting point of the core boron particle (2077 °C at 1 atm). The oxide shell melts before the solid core during particle heating, and a diffusion-controlled process is initiated through the molten shell [6]. Numerous research has been conducted to study methods that promote boron ignition and combustion [7,8].

Yetter et al. [9] reviewed the classifications of metal combustion on the basis of thermodynamic considerations and the different types of combustion regimes of metal particles. They thought that nanoenergetic particles have numerous characteristics that are attractive for fuels and energetic materials. The majority of the highly desirable traits of nanosized metal powders in combustion systems have been attributed to the high specific surface area and

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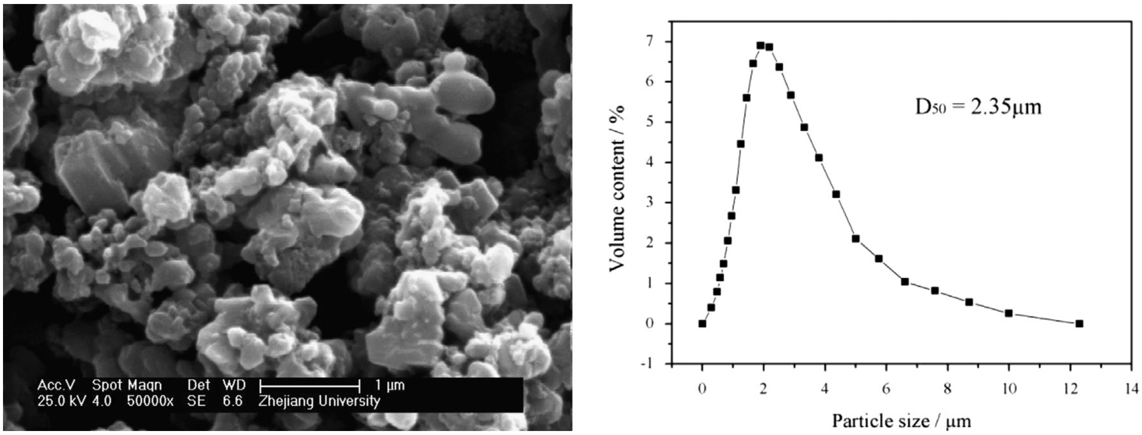

Fig. 1. SEM image (*left*) and size distribution (*right*) of boron particles.

potential energy-storage ability of such powders. The combustion rates of materials with nanopowders increase significantly compared with similar materials with micron-sized particles.

Wu et al. [10] investigated the combustion of metalized propellants and corresponding blank propellants to evaluate the actual effects of metals in solid rocket applications. The metals used in the propellants included aluminum, magnesium, boron, nickel, and Mg–Al alloy. The results showed that reactive metals can be used as energetic components in solid rocket propellants. These metals improve the combustion properties of solid rocket propellants at high pressures (>15 MPa). The use of nickel significantly stabilizes the combustion process of solid rocket propellants, whereas boron is one of the prominent additives in solid rocket propellants. Combustion efficiency can be greatly enhanced by using magnesium.

Liu et al. [11] studied the effects of boron particle surface coatings on the combustion of solid propellants. The materials selected for boron coating included LiF, Viton A, and silane. The results indicated that the LiF propellant exhibits the most significant overall behavior. The LiF and Viton A propellants have the shortest and longest ignition times under the same heat fluxes, respectively. The ignition process is dominated by ammonium perchlorate decomposition under low fluxes and may change to a condensed phase reaction under high heat fluxes.

Obuchi [12] investigated the effect of magnalium on the ignition delay time and combustion efficiency of boron. Magnalium was selected as the ignition source of boron. The ignition delay time was measured with an electronic furnace, and combustion efficiency was obtained by using a connected-pipe ducted rocket. The ignition delay time of the mixture can be divided into two regions, namely, earlier and later regions, compared with that of the single magnalium particle. When mixed with magnalium, boron can ignite below the ambient temperature single boron cannot ignite in. By adding magnalium, the combustion efficiency of the gas-generator containing boron can be improved.

Mestwerdt et al. [13] studied the combustion characteristics of a boron/lithium mixture. An electrical resistance furnace was used with a graphite tube to run tests at temperatures higher than 1727 °C. The ignition and combustion of the particles were analyzed by photographic equipment and spectrography. The results showed that the ignition temperature of boron can be lowered from 2227 °C to 527 °C by using lithium additives (the mole ratio of boron/lithium was 2.5). The combined use of boron and lithium results in a low ignition temperature and complete combustion. The reaction mechanism was interpreted by the start-up phase of a lithium flame that heated the particle to the onset of boron reaction.

Few reports have been made on the low temperature as well as high temperature ignition and combustion of boron. In this study, thermobalance was used to investigate low temperature reactions and a laser ignition facility was used to determine the high temperature ignition and combustion of boron and a Mg/B mixture. This study aims to investigate the effect of magnesium on the burning characteristics of boron particles, specifically the influences of magnesium addition on flame intensity, boron ignition delay time, boron combustion efficiency and initial temperature of boron oxidation.

2. Experimental

2.1. Materials

The boron particles (amorphous boron, purity 99%, particle size ~1 μm) used in our experiments were obtained from Yingkou Liaobin Meticulous Chemical Co., Ltd. (China). Fig. 1 shows the scanning electron microscopy (SEM) image and size distribution of the boron particles. The boron particles comprised sub-micron-sized boron regiments. The laser particle size analysis results showed that the median diameter (D_{50}) of the boron particles was 2.35 μm. This amount was slightly different from the value indicated by the manufacturer (~1 μm). The magnesium powder (metals basis, purity 99.99%, particle size ~1 μm) used as the additive was purchased from Aladdin Industrial Corporation (China).

Five mixtures of boron and magnesium were created by using magnesium-to-boron ratios (based weight) of 0.1, 0.2, 0.3, 0.4, and 0.5. The Mg/B mixtures were prepared in a mortar. For each mixture, 2 g boron and 0.2/0.4/0.6/0.8/