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Combustion characteristics of extruded double base propellant based on ammonium perchlorate/aluminum binary mixture

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ABSTRACT

Much attention has been directed toward the development of modified double base (MDB) propellant as it can offer high specific impulse as well as wide range of burning rate. One of the main approaches for the development of MDB propellant is the integration of potential oxidizers and metal fuels. This study reports on, the impact of potential oxidizers including potassium perchlorate (KP) and ammonium perchlorate (AP) on combustion characteristics of double base (DB) propellant. The impact of these energetic additives on burning rate and the characteristic exhaust velocity of gaseous product (C^*) were evaluated using small-scale ballistic evaluation test motor. The two potential oxidizers KP and AP exhibited controversy effects; whereas KP positively impact the burning rate, AP positively impact C^*. The partial replacement of AP with aluminum metal fuel demonstrated a positive impact on both the burning rate and C^*. Aluminum metal fuel offered an increase the combustion temperature, and propellant thermal conductivity. Consequently, it could alter the combustion mechanism, by thinning the induction zone, allowing the luminous flame zone to be more adjacent to the burning surface. Accordingly, the combustion reaction could proceed faster. While, MDB based on AP/Al were found to be more energetic with an increase in calorific value to reference formulation using bomb calorimetery; they exhibited good thermal stability in terms of ignition temperature using cook off test, and accepted thermal behavior using DSC.

1. Introduction

Modified double base (MDB) propellants are evolved from double base (DB) propellant by integrating energetic fillers such as energetic nitramines (i.e. HMX or RDX) [1–3]. Another trend is to integrate potential oxidizers such as ammonium perchlorate (AP), and potassium perchlorate (KP) as well as active metal fuels such (i.e. aluminum and boron) [2,4,5]. MDB propellant can offer wide range of burning rate and specific impulse [6]. Consequently, MDB propellant has found wide applications in booster, sustainer, and dual thrust rocket motors [7]. Furthermore, it has been employed in tactical missiles due to its advantages including [1,2,8,9]:

- Superior mechanical properties
- Excellent operational characteristics
- Good aging capabilities

Thrust is the force produced by a rocket propulsion system acting upon a vehicle; it can be represented by Eq. (1).

$$F = \dot{m}V_2 + (P_2 - P_3)A_2 \quad (1)$$

The first term is the momentum thrust; represented by the product of the gaseous mass flow rate ($\dot{m}$) and its exhaust velocity (V_2). The second term represents the pressure thrust; it consists of the product of the cross-sectional area at the nozzle exit (A_2) and the difference between the exhaust gas pressure and the ambient fluid pressure ($P_2 - P_3$). Fig. 1 is a schematic for pressure distribution inside solid rocket motor.

Specific impulse is the thrust imparted to a vehicle per combustion of unit weight of effective propellant. The two main criteria of rocket propellant which need to be precisely evaluated and

Abbreviations: DB, double base; MDB, modified double base; KP, potassium perchlorate; AP, ammonium perchlorate; C^*, characteristic exhaust velocity of gaseous product; Al, aluminum metal; DSC, differential scanning calorimetery; $\dot{m}$, mass flow rate; A_2, cross-sectional area at the nozzle exit; P_2, exhaust gas pressure; T_o, initial temperature of the solid phase reaction; T_u, onset temperature of the solid phase reaction; T_s, burning surface temperature; NC, nitrocellulose; NG, nitroglycerine; I_{PT}, total impulse; A_t, throat area; W_t, propellant mass; P_3, ambient fluid pressure.

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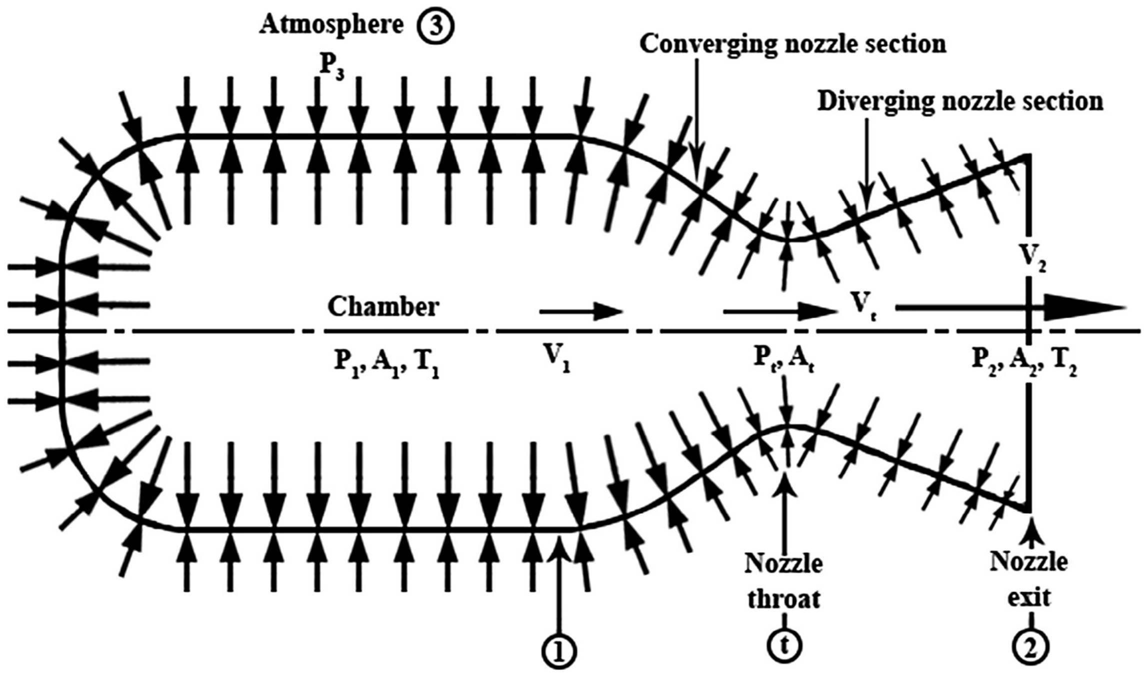

Fig. 1. Pressure balance on chamber and nozzle interior walls, where P_1 is the chamber pressure, P_t is the throat pressure, and P_2 is the exit pressure [8].

measured are burning rate and specific impulse [10]. These two main parameters can be optimized and/or maximized via controlled combustion mechanism of DB propellant.

1.1. Combustion mechanism of DB propellant

The combustion rate of solid rocket propellant is expressed as a regression from the burning surface [11,12]. It is widely accepted that the combustion wave of DB propellant consists of five distinctive zones (Fig. 2) [13,14].

1.1.1. Heat conduction zone

No chemical changes occur at this zone. Thermal effect by heat conduction from the burning surface causes temperature increase from the initial temperature (T_o) to the onset temperature of the solid phase reaction (T_u).

1.1.2. Solid phase reaction zone

It is a very thin layer; temperature in this zone is approximately equal to the burning surface temperature (T_s). The overall reaction in this zone seems to be exothermic.

1.1.3. Fizz zone

This zone is just above the burning surface; where a series of degradation reactions occurs very rapidly.

1.1.4. Induction zone

In this zone, very slowly oxidation reactions occur.

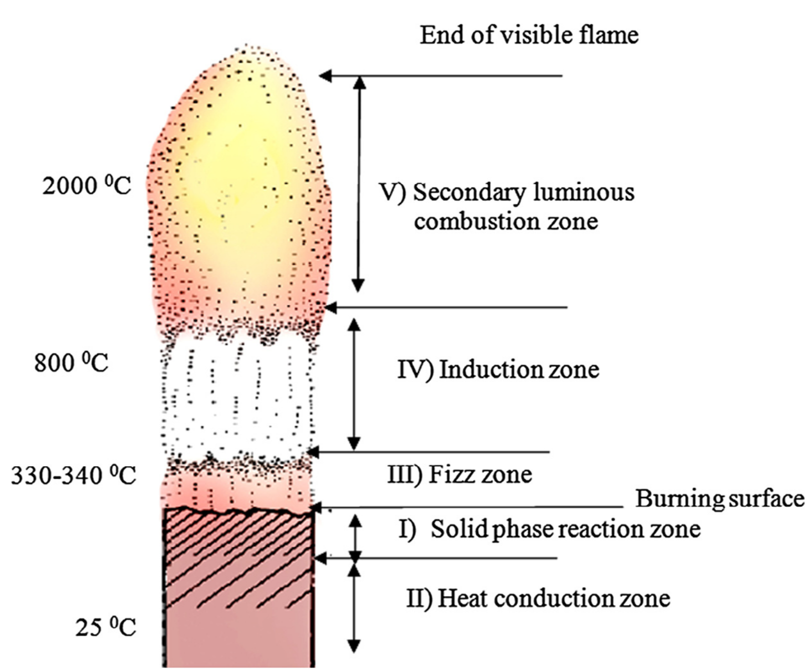

Fig. 2. Distinctive combustions zones of DB propellant with associated chemical reaction [15].