The Experimental Analysis of the Combustion Characteristics of the Electrically Controlled Solid Propellants with Various Metal Composition*

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The propulsion system based on electrically controlled solid propellants has been introduced to cover the demerits of the conventional solid propellant. Thrust generated by the system can be adjusted by controlling the burning rate. In this research, the overall combustion characteristics of the electrically controlled solid propellants were investigated. In addition, the amount of the metal additive was varied by 5% and 15% in weight. Depending upon the amount of metal content, two distinct regions were seen in the electric power signals, designated as region I and II. Between the two regions, the differences in the combustion characteristics could also be seen clearly. A constant electric power was observed in region I, whereas a linearly increased trend in power was detected in region II. Irregular or intermittent combustion occurred druing region I. However, gradual downward burning occurred in region II.

Key Words: Electrically controlled solid propellant, Electric signal, High-speed image, Burning characteristics

1. Introduction

The solid propellant system is being used solid rocket motors and several other operations because of the advantage of being able to store the propellant safely and operate rapidly. The conventional solid propellant system, however, cannot overcome serious shortcomings such as thrust-control. Due to this lack of the controllability, electrically controlled solid propellant (ECSP) system has been introduced. ECSP only burns when sufficient amount of external electric power is applied to the propellant. Moreover, the burning rate of ECSP could also be regulated by changing the percentage of metal additives in the composition. Through these characteristics, ECSP has been attracting lot more attention in the field of propellants as an alternative to the existing solid propellant, as ECSP can overcome the drawbacks of conventional solid propellants. In earlier research, a few different types of ECSP compositions were studied and examined. Sawka et al. [1] studied burning characteristics of ammonium nitride (AN) and hydroxyl ammonium nitrate (HAN)-based ECSPs. Gobin et al. [2] analyzed the effect of the composition of polyethylene oxide (PEO), lithium perchlorate (LP), and ammonium perchlorate (AP) on burning rate and electric characteristics. Zamir et al. [3] observed the effects of pressure and voltage on the burning characteristics. In particular, HAN-based ECSPs have been widely studied among different types of ECSPs. Bao et al. [4] found the effect of few parameters on ignition, burning, and extinguishment characteristics. Gnanaprakash et al. [5] conducted thermal analyses and found out the decomposition characteristics. In the present research, therefore, the burning characteristics of the LP-based ECSP was experimentally analyzed by using several measurement techniques.

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2. Methodology

2.1. Sample composition

In this study, ECSPs with two compositions were used as test targets. Tungsten (W, US Research Nanomaterials Inc., particle size of 1 μm) was used as a metal additive, which could affect the burning charactersitcis. LP (Alfa Aesar Ltd., 99% purity) and Polyvinyl alcohol (PVA, Sigma Aldrich Ltd., >99% hydrolyzed, molar weight of 146,000-186,000) were used as the oxidizer and fuel, respectively. In addition, glycerol and boric acid (H_3BO_3) were used as the plasticizer and crosslinking agent, respectively. Detailed compositions of the propellants are listed in Table 1.

Table 1. Compositions of ECSPs.

Contents (wt%)	M5 (W 5%)	M15 (W 15%)
H_2O	50.63	44.14
LP	27.37	23.86
PVA	10	10
W	5	15
Glycerol	5	5
H_3BO_3	2	2

2.2. Experimental setup

The experimental setup of present research is shown in Fig. 1. The propellant was mounted between upper and lower electrodes, which was made of molybdenum (Mo). Through the electrodes, 300 V of external voltage was applied to the propellant using a power supply (1 kV and 1A). The voltage and current probe were installed between the power supply and oscilloscope (Teledyne, WaveSurfer 3104z, 1 GHz bandwidth, 4 Gs/s sampling rate) to measure the voltage and current simultaneously. In addition, high-speed camera (Vision Research, Phantom V711, 1000 Hz, 100 μs exposure time, 800 × 600 pixels) was also connected to the oscilloscope to gather the flame image at exact time.

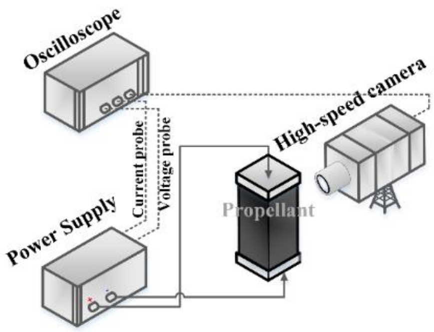

Fig. 1. The experimental setup

3. Results

3.1. Electric signal

In Fig. 2, acquired electric power signals during the combustion process are displayed. X-axis shows the time cycle of ECSP burning, 0*T* represented the time when the 300 W of electric power was applied to the propellant and 1.0*T* represented the time when the propellant was completely burned (T_{end}). Durning the total burning period, two distinct regions could be recognized; region I and II. In region I, measured power was almost constant, whereas the power increased linearly in region II. At the same time, the transition time (T_{trans}) from region I to region II was delayed with the increase in the metal content in the ECSP propellant. Additionally, it was observed that more power was required to burn ECSP with a low metal content due to low electrical conductivity.

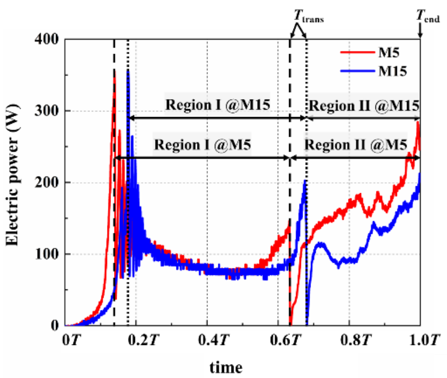

Fig. 2. Electric power distribution during the overall combustion

3.2. Burning characteristics

Figure 3 shows a series of burning images for M5 and M15. In region I, the intermittent burning was dominant. In other words, sparse flame spots were generated on the front and rear surfaces of the propellant. In region II, however, the gradual downward burning was dominant. This means that most of the propellant was burned in region II. Futhermore, a faster regression in propellant length was observed in region II.

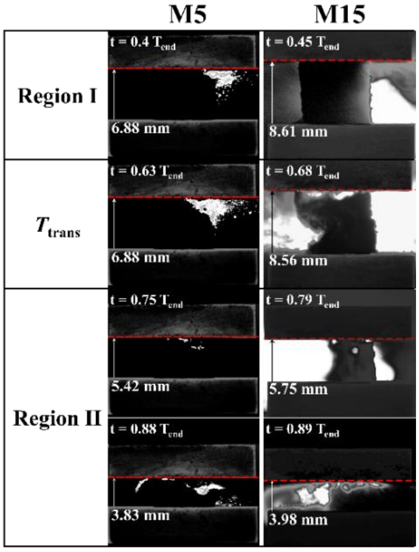

Fig. 3. Burning images in greyscale

4. Conclusion

The present research in this paper focused on the burning characteristics of ECSP with different metal content. Based on the electric signal acquisition, these signals could be divided into two regions based on transition time. The different burning characteristics could also be detected between region I and II. Intermittent burning was leading in region I, while burning with gradual regression was leading in region II.

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