別紙４－１（課程博士（英文））

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Abstract (Doctor)

Title of Thesis	Study of Burning Characteristics of a Porous Combustible Soaked in a Liquid Oxidizer

Approx. 800 words

With an increasing trend in development of smaller satellites owing to significant progress in microelectronics, and together with an increasing awareness of threats to the environment, a dedicated small launch vehicle for launching the smaller satellites, employing environmentally friendly propellant are becoming highly demanded. To respond this, a hybrid rockets have been promising for the launch vehicle and of great interest by many research groups. Although great efforts have been made ever, its practical application as the launch vehicle has been found to be challenging.
In 1997, Nagata et al. proposed a simple propellant consisting of a porous combustible soaked in a liquid oxidizer. They made an experimental investigation of pressure dependency on regression rate of the propellant, and it was found that the propellant could achieve excellent thrusting performance comparable to the existing chemical rocket systems. On the other hand, unwanted burning behaviors, such as an explosion-like burning, were frequently observed in their experiments, and data scattering of the regression rate was measured at random pressure in their experiments. In addition, the burning characteristics have been limited to the pressure dependency on the regression rate since 1997. For guaranteeing safety and reliability of the propellant while leveraging its excellent thrusting performance, it is necessary to obtain comprehensive knowledge of the fundamental burning characteristics of the propellant and clarify the reason for the unwanted burning and the data scattering as fundamental research. In this work, as referred to the previous work by Nagata et al., comprehensive experimental and numerical investigations on the fundamental burning characteristics of the propellant were conducted.
Comprehensive experimental investigations to obtain the fundamental burning characteristics of the specimen, consisting of a polyethylene foam soaked in enriched hydrogen peroxide, were conducted. To examine the fundamental burning characteristics, such as burning behavior, regression rate, its steadiness, thermal structure during entire burning event, and one-dimensionality of burning process, an experimental setup, testing methodology, and a simple thermal analysis were introduced. Experiments in nitrogen-filled environment were carried out at various pressures (0.1 MPa – 0.35 MPa) and fuel porosities (0.6 – 0.9) to obtain those of the fundamental burning characteristics. It was found that an end-burning at which top surface (burning surface) of the specimen moves downward at reasonably constant rate is successfully achieved under the conditions studied in this work. From results of the direct observation during the burning event and direct temperature measurements by thermocouple, it was revealed that progress of the tested specimen shall be dominated by the premixed-like surface flame established in the vicinity of the top surface. Furthermore, it was proved that the one-dimensionality of the burning process shall be valid by the simple thermal analysis. These facts helped to develop a simple burning model under assumptions; the steady state, premixed combustion, and one-dimensionality.
Based on the experimentally obtained facts, a simple one-dimensional burning model was then developed to numerically investigate the fundamental burning characteristics. The thermal structure and the potential regression rate under various prescribed conditions were predicted using the burning model developed in this work. Separately considering the estimated blow-off limit in the gas-phase over the top surface by CHEMKIN (PREMIX-code), a range needed to achieve successive burning was numerically predicted. The effects of oxidizer type (hydrogen peroxide and liquid oxygen), the

fuel porosity, and pressure on the potential regression rate, the thermal structure, and blow-off limit were then discussed. Findings show that the successive burning is widely achievable when hydrogen peroxide is used as the liquid oxidizer, but it is only partially achievable when liquid oxygen is utilized. This fact may support the data scattering and the behavior observed in the previous work reported by Nagata et al.

Product gases of the burning specimen at nitrogen-balanced 0.1 MPa ambient to predict thrusting performance of the present specimen were studied. In the experiments, we first measured one-dimensional (1-D) CO_2 and H_2O concentration profiles over the regression surface by a gas chromatography under various fuel porosities 0.77 – 0.84. The concentration profiles exhibited nearly flat, suggesting that chemical equilibrium was reached satisfactory immediately after the regression surface. The equilibrium calculation was then utilized in order to predict optimal combination of pyrolysis gases, oxidizer gases, and their mass fraction, and estimate the other product gases potentially produced and thrusting performance achievable in this burning specimen. Two important facts were noted: (1) the predicted mass fraction of oxygen shall be lower than that of pure H_2O_2 and (2) major pyrolysis gases components were found to be methane (CH_4), ethylene (C_2H_4), and ethane (C_2H_6). Expected specific impulse potentially achievable by the present burning specimen was estimated and found to be in the range of 95 s to106 s, depending on the initial concentration of H_2O_2. This fact implied that using pure H_2O_2 was preferred to achieve the larger specific impulse of the present specimen.