A performance comparison of electrically controlled solid propellants of selective metal additives*

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This paper is an attempt to understand the effect of various metal additives in the electrically controlled solid propellants (ECSP). In recent times, there is a growing interest in utilizing the controllable solid propellant combustion that facilitates multiple start and stop bits of the ECSP combustion at will. This task was accomplished by means of varying applied electrical power to vary the steady state mean burning rate instantaneously in the voltage range of 150 V to 300 V and this concept can be used for powering the micro thrusters to control the attitude of the satellites in the deep space mission. The present study incorporates the usage of magnesium, aluminium and titanium as the metal additives to understand the effect of metal additives by combusting the ECSP in the open atmospheric conditions. These metal additives were added to the baseline ECSP composition in which lithium perchlorate (LP) as an oxidizer and polyvinyl alcohol (PVA) as binder/fuel are the main ingredients. Thermal analysis, differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA), of these compositions revealed that the magnesium based ECSP has higher thermal stability as compare to any other ECSP compositions considered in this study. The decomposition temperature for the Mg based ECSP is always above 400 °C which is not particularly seen in any other composition so far. Also, when the magnesium (Mg) is added to the baseline composition the combustion ceases, which is peculiar behaviour of Mg reported first time in this paper.

Key Words: ECSP, Differential Scanning Calorimetry, Thermogravimetric Analysis.

1. Introduction

Electrically controlled solid propellants (ECSP) are a type of propellant that only ignites when a substantial quantity of electric power is provided externally and totally stops when there is no electric power. This pyroelectric behavior ECSP allows them to utilize it as a multiple start and stop bit in space applications for managing satellite attitude by applying these ECSP in micro thrusters, pulsed plasma thrusters, gas generator systems, and long-range rocket motors. ECSP may also be used to construct a very stable rocket engine with a broad variety of operating frequencies due to their better stability, variable throttle, establishing multiple impulse bits and changeable burning rate by changing the electrical power supply.

Sawka et al.1) developed a hydroxyl ammonium nitrate (HAN)-based composition and exhibited ECSP applicability in micro to macro propulsion technology by completing tests in a closed bomb setting up to 6.8 MPa.

When graphite is added to the HAN-based ECSP, Bao et al.2) explored its effects and found that the carbon increases thermal conductivity at the expense of adiabatic flame temperature reduction, which influences the propellant's specific impulse (Isp). In order to enhance the mechanical characteristics of the ECSP, Gnanaprakash et al.3) added glycerol and boric acid in addition to the same base composition (LP/PVA based) as He et al.4), which was identical. The decomposition temperature dropped by 60°C with the addition of W compared to non-metallized ECSP. Additionally, it was observed that the addition of the W particles decreased the ECSP's thermal stability.

The literature makes it clear that not enough research has been reported in order to fully understand how different metal contents in the composition of the ECSP compare to conventional propellants. The impact of different metal additions when mixed with the ECSP's basic composition and their thermal analyses are presented in this research. This study aims to comprehend the metal influence on ECSP because no similar studies have been previously published.

2. Experimental Setup

2.1 Propellant preparation

Lithium perchlorate (Alfa Aesar Ltd.), an oxidant with a purity of 99.0%, polyvinyl alcohol (Sigma-Aldrich Ltd.), a binder/fuel with a molecular weight of 146,000–186,000 and a degree of hydrolysis > 99.0%, and boric acid (H3BO3), a cross-linking agent, are the major components of ECSP samples. Metal fuel additives include aluminum (US Research Nanomaterials) with a particle size of 10 m, titanium (US Research Nanomaterials Inc.) with a particle size of 800 nm, and magnesium (US Research Nanomaterials Inc.). The weight ratio of LP to water during propellant manufacture was kept at 1:1.85, which is just over the solubility limit. With Mg as 5% in one composition, 1% Ti in another, and 1% Al in the third, three distinct compositions were created. After LP and PVA were dissolved in the water, the propellant components were homogenized using a planetary centrifugal mixer (Thinky ARE-310, Japan) for a total of 45 minutes.

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2.2 Characterization method

Differential scanning calorimetry (DSC 3+, Mettler Toledo) and thermogravimetry (TGA 2, Mettler Toledo) were used for the thermal investigation of the ECSP samples, in order to characterize them at various heating rates of 10 °C /min and 20 °C /min.

3. Results and Discussion

3.1. Flame visualization.

The flame visualization of various ECSP's with different metal additives has been conducted using the DSLR camera at 24 frames per seconds as the shutter speed. The montages of images in Fig.1 shows the burning of the Titanium based ECSP sample, which shows the erratic burning behaviour.

Figure 1: Burning sequence of Titanium based ECSP.

ECSP samples were burned at different voltages and it is found that the formation of the liquid layer at lower voltages enhances the combustion process by distributing the decomposed products of the LP and PVA in the surrounding area of the ECSP where the contact of the electrode happens, thus formation of the liquid layer ensures the adequate combustion. The formation of the condensed phase liquid is only seen at the low voltage conditions and not at the high voltage conditions. Whenever the voltage is supplied to the ECSP samples, first liquid layer is formed but the same behaviour is not seen in the Mg based ECSP samples. This behaviour of the Mg in the ECSP samples is reported first time.

3.2. Thermal analysis.

Thermal analysis of the ECSP samples with different metal additives were conducted to obtained the heat of reaction and understand the thermal behaviour of the ECSP. It is observed that the thermal stability of the magnesium based ECSP is much pronounced as compared to any other ECSP samples with other metal additives. The decomposition of the magnesium based ECSP sample happens in the range of 400 °C - 500°C as compare to two other ECSP samples with aluminium and titanium that happens in the range of 300 °C – 400 °C. Figure 2 shows the DSC curve of various ECSP samples with different metal additives. Figure 3 shows the TGA and dTG curve of the three ECSP samples considered in this study. Mass loss of the aluminium-based compositions is higher as compare to the titanium and magnesium based ECSP samples. It is noticed that the mass loss of the magnesium based ECSP is lesser among the three compositions by well over 50%.

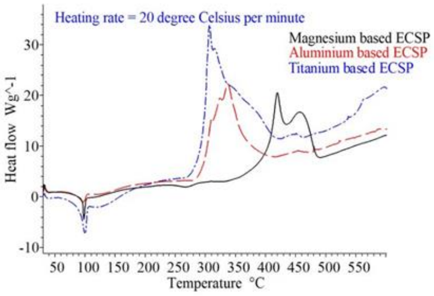

Figure 2: DSC curve of three ECSP compositions

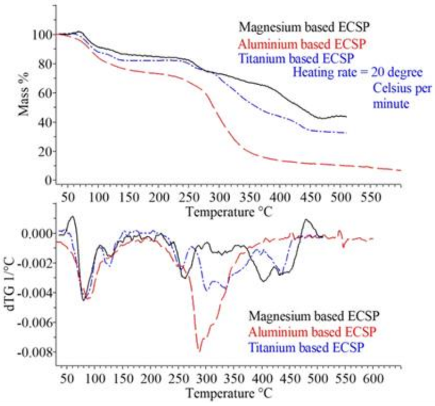

Figure 3: TGA and dTG curve of three ECSP compositions.

4. Conclusion

This study presents the characterization of the ECSP samples with three different metal additives. It is observed that the thermal stability of the magnesium based ECSP samples are higher than the aluminium or titanium based ECSP samples. It is also noticed that the formation of the liquid layer during the burning of the ECSP under atmospheric conditions enhances the conductions thereby allows for the uniform combustion of the samples locally.

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