ABSTRACT

Hybrid rocket fuels are considered safer compared to solid and liquid based rocket fuels due to operational and handling reasons. The thermal stability and combustion capability are important aspects determining the usability and their efficiency. The solid fuel of hybrid rockets has drawbacks such as low fuel regression rate and varying oxidizer-to-fuel ratio during the combustion. The diffusion-limited combustion in hybrid rocket motor is the main cause for low regression rate and poor combustion efficiency in solid hybrid fuels such as Hydroxyl-terminated polybutadiene (HTPB), Poly methylmethacrylate (PMMA) and other polymeric binder-fuels. The paraffin-based solid fuel impresses as a potential solution to solve the slow regression problem of traditional solid polymeric fuels. However, the paraffin-based fuels suffer from poor mechanical properties and rapid volatilization, preventing its full development and application for a space mission.

In the present work, the physical, thermal and ballistic performance of paraffin-based fuel blended with Low-density polyethylene (LDPE) and loaded with Aluminum (Al) and Boron (B) additives were investigated. The premise behind blending LDPE is to increase the mechanical strength and the metallic additives is to compensate for the loss of regression due to polymer blending. The paraffin-based fuels were prepared using varying weight percentages of polyethylene (PE) as a binder and Al and B as energetic additives. The thermal decomposition/combustion studies were carried out on paraffin blended Polyethylene (P/PE)-based solid hybrid fuels incorporated with metallic additives under N$_2$ and O$_2$ environment using Differential Scanning Calorimeter (DSC). The metallic additives such as Aluminium (Al) and Boron (B) were added to increase the energy density. It was observed that the combustion initiation temperature to be same for additive samples, whereas the upward shift in the peak decomposition temperature for Al...
compared to B. The Al and B-based samples exhibited higher heat release compared to pure paraffin samples. The peak decomposition temperature increased with increasing additives concentration in the paraffin/PE matrix indicating the metal additives may be contributing to thermal stability. The kinetic parameters of thermal decomposition and combustion were evaluated and discussed for 5% by weight loading of Al and B additives.

The ignition performance, combustion characteristics and exothermic behavior of these paraffin-based fuels were studied through Thermogravimetry/Derivative thermogravimetry/Differential scanning calorimetry (TG/DTG/DSC) experiments. The addition of PE increased the ignition and combustion temperature, whereas the incorporation of metallic additive lowered the decomposition temperature. The heat of combustion of paraffin-based fuel samples increased as the Al and B loading content was increased from 5 wt.% to 25 wt. %. The ignition and combustion indices were calculated to evaluate the ignitability and oxidation ability of the fuels. The rheological investigation indicated that the addition of PE to paraffin had increased the melt layer viscosity whereas the effect of the Al and B powders on viscosity was small. The increase in viscosity has helped in controlled volatilization. The ballistic tests were performed under gaseous oxygen and the results revealed that the regression rate decreased with increasing PE content (5 wt. % to 10 wt. %) in the paraffin wax. The addition of Al and B increased the regression rate compensating for the loss of regression rate due to PE addition.

These formulated paraffin-based fuels were tested for mechanical characterization. The pure paraffin sample was used as the reference. The tensile tests were performed to evaluate the ultimate tensile strength, elastic modulus, and percentage elongation at break. The ultimate tensile strength of the P/PE formulation increased from 14% to 39% with the increase of PE
loading from 5 wt. % to 15 wt. % and the elastic modulus was found to increase from 114.36 MPa to 129.27 MPa. For the P/PE formulation, the addition of B enhanced the tensile strength from 32.7% to 47.13% with the loading of B content increased from 5 wt. % to 25 wt. %. The compression tests showed significant improvement in compression strength and elastic modulus with the addition of PE, Al, and B to pure paraffin wax. At 25 wt. % Al loading, the compression strength increased about 63.2% as compared to pure paraffin formulation. The effect of additives on the formulation and the optimal loading ratio were also discussed without compromising on the regression factor. It can be concluded that poor mechanical properties of paraffin-based solid fuel can be improved with the addition of PE.