CHAPTER 7
SUMMARY

In the present work, the thermal, mechanical and ballistic performance of paraffin-based solid fuel was investigated using PE, Al and B as additives. The fuel samples were prepared by the typical melt mixing process and the Al and B additive was uniformly dispersed within the P/PE blend. The thermal decomposition of paraffin-based solid fuel under N₂ and O₂ environments has been carried out. DSC experiments conclude that the melting enthalpy of paraffin-based fuel formulations decreased as the additive concentration increased from 5 wt.% to 25 wt.% The reduced melting enthalpy is attributed to the lower crystallinity of the pure paraffin wax in the fuel formulation. The addition of metal additives in paraffin-based fuel increased the peak exothermic temperature. The P/PE/B sample exhibited a significantly higher heat release in the presence of oxidizing environment as compared to P/PE/Al.

Kinetic study was performed with 5 wt.% additive in the fuel formulation. It was observed that the addition of additives in the paraffin does not significantly influence the activation energy. The presence of oxygen during the exothermic reaction greatly accelerated the paraffin-based fuel decomposition. The activation energy obtained by Ozawa method agreed reasonably well with that obtained by Kissinger method for both pyrolysis and combustion.

The tensile and compression tests were performed on paraffin-based solid fuel to improve the mechanical properties and explore their feasibility for hybrid rocket launch vehicle application. The results indicated that the addition of PE in paraffin-based solid fuel has significantly increased the ultimate tensile strength,
elastic modulus and percentage of elongation at break. The addition of B and Al additive in P/PE formulation showed a significant improvement in tensile strength and elastic modulus. The tensile strength of P/PE/B formulation was increased up to 89% compared to pure paraffin wax, when 25wt.% of B added in P/PE matrix. Whereas at same additive loading, P/PE/Al formulation has reported about 7.6 % improvement in the ultimate tensile strength.

The formulations doped with SA showed significant improvements in ultimate tensile, elastic modulus and percentage of elongation at break was observed. At higher SA contents, 25 wt.%, the fuel formulations exhibited significantly higher ultimate tensile strength compared to pure paraffin sample. This was attributed to better miscibility of SA in the paraffin and PE matrix. As the amount of paraffin wax decreased in formulation, the stronger interfacial locking may exist between P and PE.

Mechanical compression tests of these paraffin-based fuels showed significant improvement of compression strength and compression modulus with PE addition. The addition of Al in the P/PE blend had shown a slight improvement in the mechanical properties. These results indicate that the mechanical properties are significantly enhanced with these formulations; nevertheless, these formulations may slightly decrease the ballistic performance in a hybrid rocket. However, these mechanically stiff paraffin-based fuels could withstand the stress loads, radial combustion pressure, and axial thrust load during the operation.

The ignition behavior and combustion characteristics of fuel samples were investigated by the TG/DTG/DSC technique and it is seen that ignition and burnout temperatures of the paraffin wax was increased considerably with PE
addition. Furthermore, the Al and B addition to P/PE blend led to significantly lower the ignition and decomposition temperatures. The burn out temperatures of these paraffin-based fuels indicated that the reactivity of PE and paraffin during the combustion decreased as percentage of PE increased in the P/PE blend. The addition of Al and B has increased the reactivity during combustion process and dropped the peak oxidation temperature to lower values.

The DSC study showed that the addition of Al significantly improved the exothermic heat release of these paraffin-based samples which was attributed to the high thermal conductivity of Al. The large percentage of Al in P/PE blend enhances heat released, which sped up the oxidation reaction and accelerate the exothermicity of fuel sample. Similarly, the P/PE/B based formulations represents the highest value of peak and burnout temperatures compared to other formulations. As the concentration of B increased from 5 wt. % to 25 wt. %, the peak and burnout temperatures are reduced to lower value but still higher than P/PE/Al formulations. DSC/TG results from this study could serve as input thermodynamic parameters for the combustion modelling of these paraffin-based fuels.

The ballistic tests were performed on a lab-scale motor with gaseous oxygen as oxidizer. It has been shown that the regression rates of P/PE samples were decreased as PE concentration increased from 5 to 10 wt. %; whereas increasing Al doping from 5 to 25 wt. % increased the regression rate by 95%. The regression rates of all P/PE/B formulations increased as the B wt. % increase in the formulation. Although the regression rates of P/PE/B were below the pure paraffin wax but still exhibited higher value than P/PE blend. The addition of Al and B in P/PE formulation showed no significant change for viscosity and hence mass entrainment mechanism to combustion zone as compared to the pure P/PE
fuel. Thus, the regression rates of P/PE/Al and P/PE/B based formulations were below the value of paraffin wax, but exhibited a higher value than that of P/PE formulations. Finally, the regression rates were correlated with the oxidizer mass flux to obtain the regression rate exponents for each set of fuel formulations.

Overall, these paraffin-based fuels are thermally stable, exhibited higher mechanical strength and ballistic performance and can be a potential candidate for hybrid rocket applications.