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Combustion Characteristics of HTPB-based Hybrid Rocket Fuels: Using Nickel Oxide as the Polymer Matrix Pyrolysis Catalyst

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Introduction

- The slow regression rate induced by the high pyrolysis difficulty has limited the application and development of HTPB-based fuels in hybrid rocket propulsion;
- The traditional methods of overcoming this intrinsic limit have their own shortcomings;
- The nickel oxide (NiO) shows the possibility of increasing the regression rate by catalyzing the pyrolysis process of the polymer matrix in our previous investigation;
- Hence investigating the NiO particles on the thermal decomposition and combustion of HTPB-based fuels .

Experiment

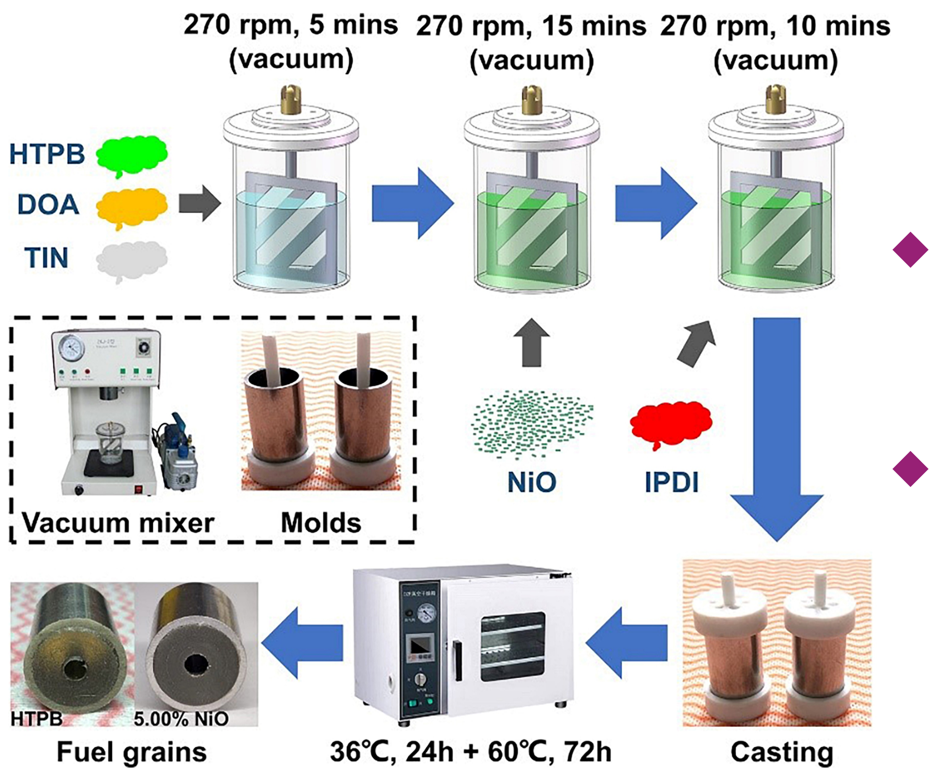

Fig. 1. Fabrication process.

- The pure HTPB and 1.25 wt%, 2.50 wt%, 5.00 wt%, 7.50 wt%, and 10.0 wt% NiO loaded fuels were prepared;
- Fuels grain size: 16 mm OD × 4.5 mm ID × 30 mm length.

- The fuel grains were tested at a quasi-steady value of 1.0 MPa;
- Gaseous oxygen was used as oxidizer.

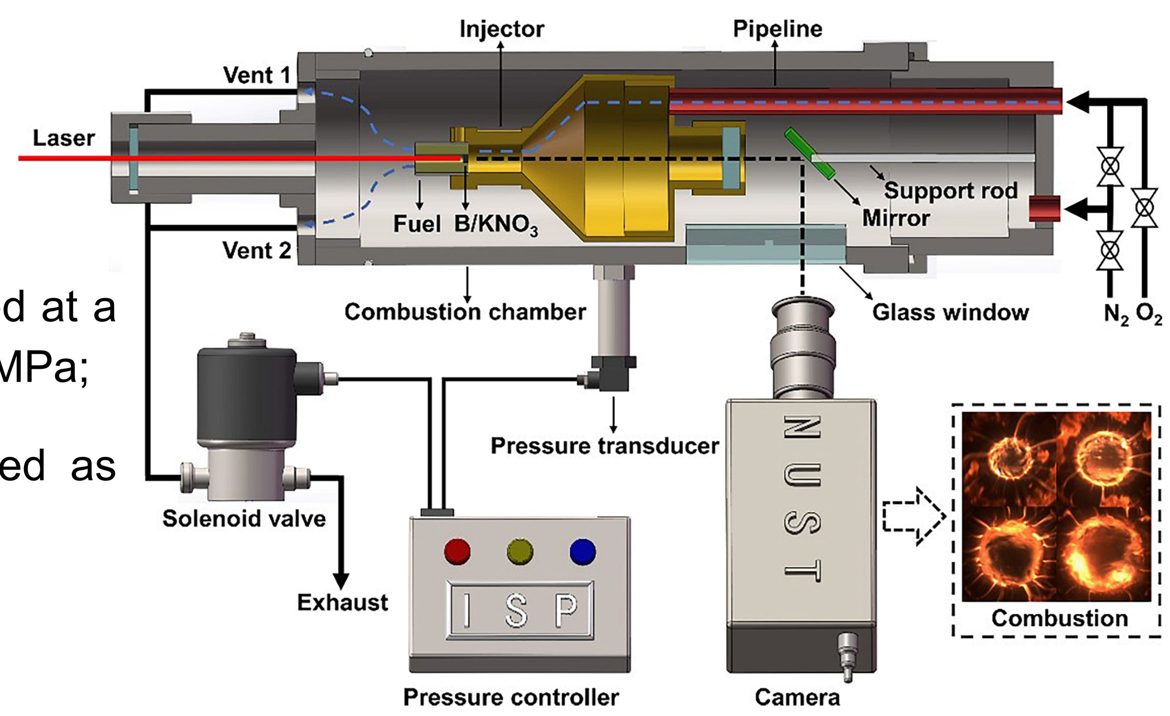

Fig. 2. Schematic of the 2D-radial hybrid burner.

Results & Discussion

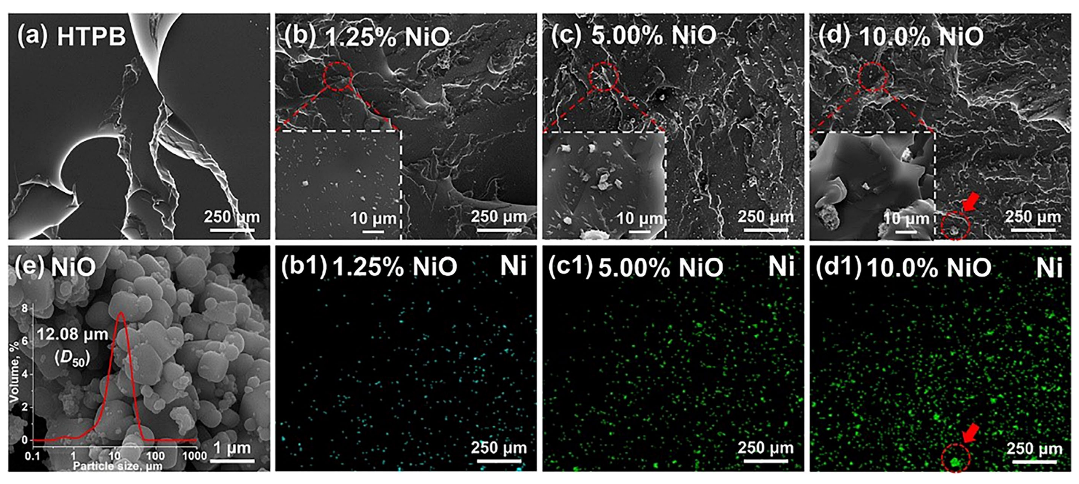

Fig. 3. Surface morphology.

- Without cracks or pores, demonstrating the feasibility of the preparation process;
- The NiO particles agglomerated in the NiO loaded fuels.

- The catalytic effect of NiO on the polybutadiene component is mainly reflected in the late-term thermal decomposition process;
- Basically no catalytic effect is shown on the other thermal decomposition stages.

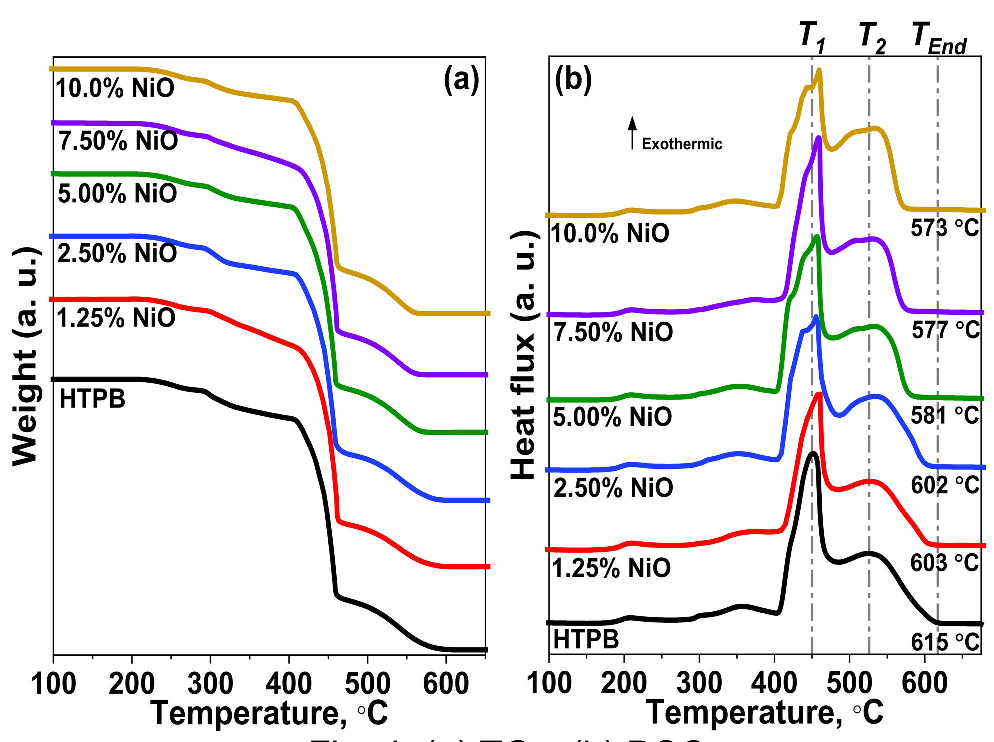

Fig. 4. (a) TG; (b) DSC.

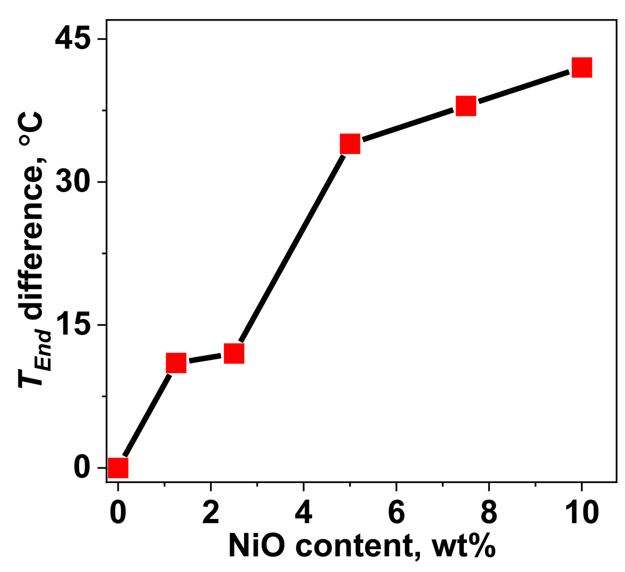

Fig. 5. The end temperature difference between pure HTPB and NiO loaded fuels.

- The catalytic pyrolysis effect will be significantly enhanced with the increase of NiO content ([NiO ≦ 5 wt%]);
- Followed by (> 5 wt%) the decrease of the benefit-cost ratio for the catalytic effect;
- NiO particles also lead to a significant increase in residue content during the pyrolysis process.

- NiO increases the thermal conductivity of HTPB-based fuels slightly (6.61% max);
- NiO loaded fuels show a flat increase in the thermal conductivity once the NiO content exceeds 2.50 wt%.

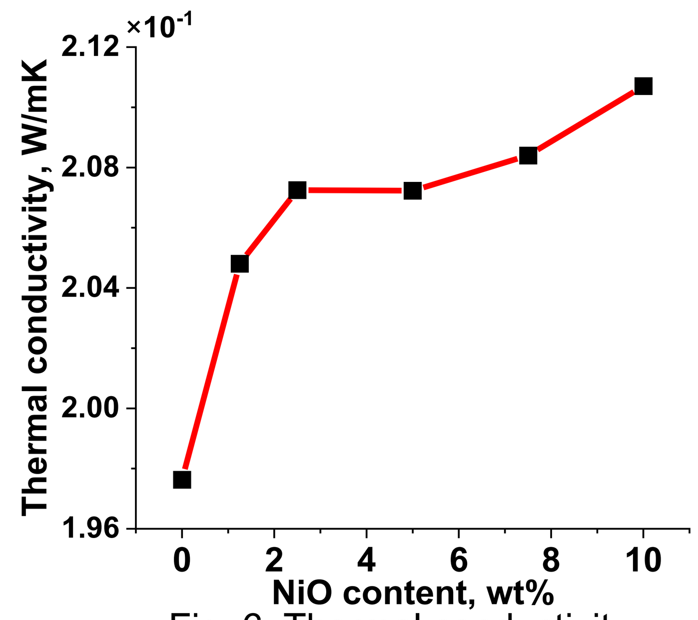

Fig. 6. Thermal conductivity.

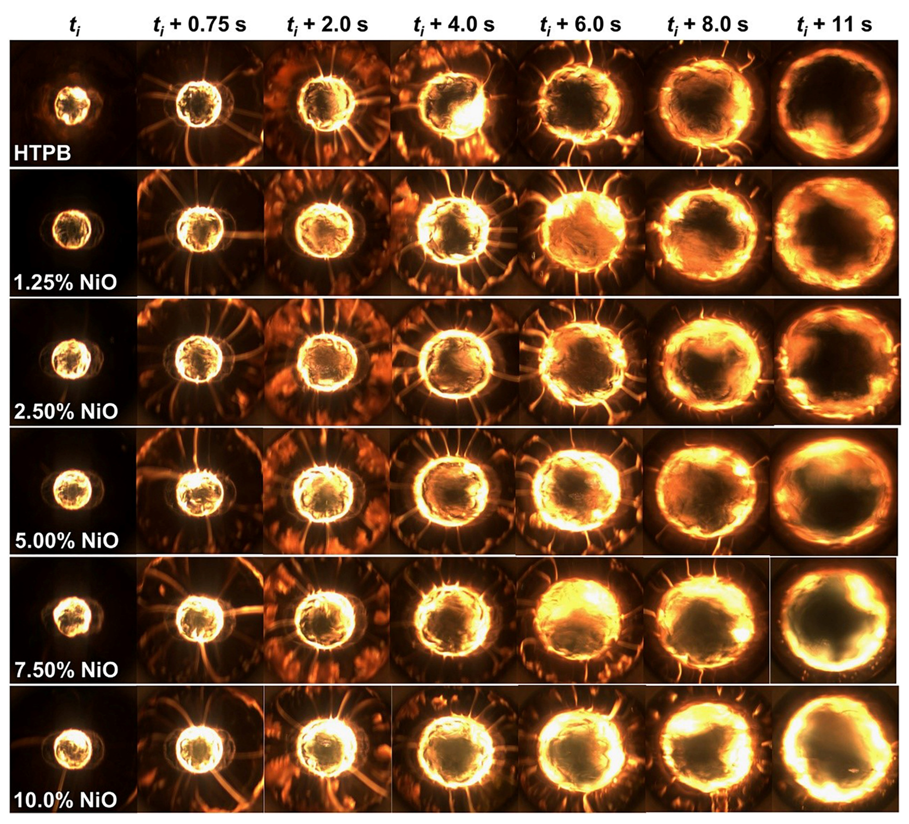

Fig. 7. Regression process.

- NiO particles accelerate the pyrolysis process of HTPB, hence promoting the burning process and resulting in more intense combustion;
- NiO also serves as the radiating particles and improves the flame brightness of the HTPB-based fuels;

- The loaded formulations feature an accumulation of NiO particles at the regressing surface;
- The slope is 0.1844 before combustion, while changed to 0.4068 after the combustion test;

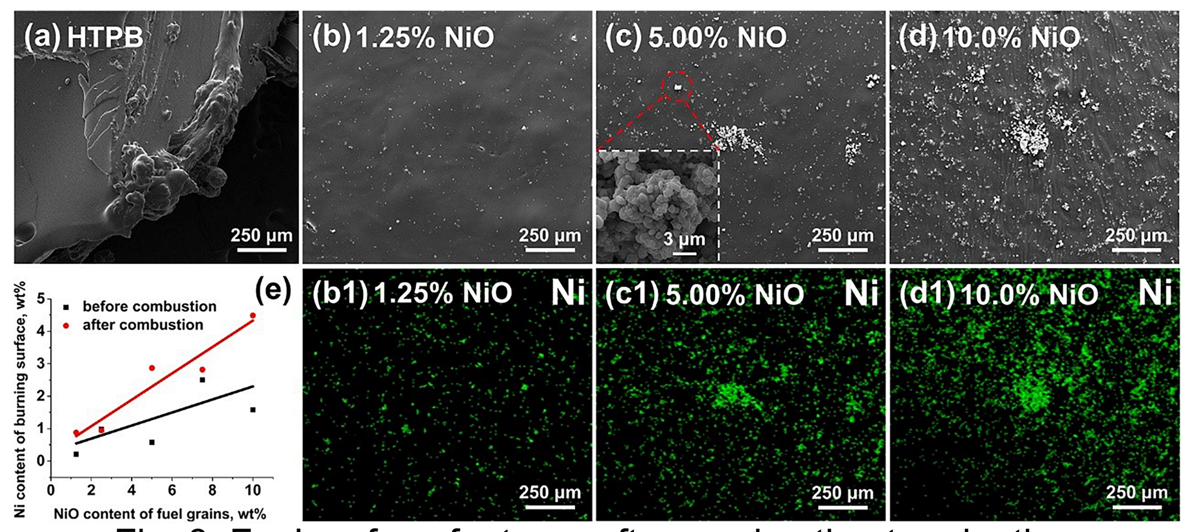

Fig. 8. Fuel surface features after combustion termination.

- NiO particles will gradually accumulate on the regressing surface, which will reduce the combustion surface area and inhibit combustion.

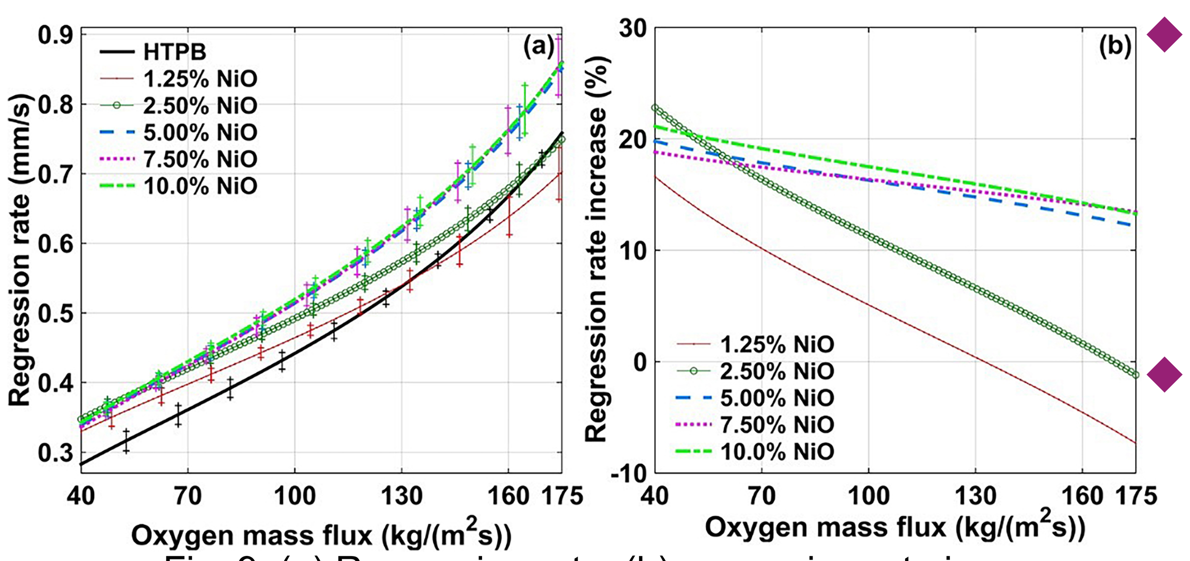

Fig. 9. (a) Regression rate; (b) regression rate increase (pure HTPB served as the baseline).

- The 5 wt% NiO enhances the regression rate by 19.4% and 13.7% at G_{ox} = 50 kg/m²s and 150 kg/m²s, respectively;
- The higher regression rate increase in the low oxidizer mass flux originates from the improved radiative heat transfer;
- Demonstrating the catalytic effect of NiO on HTPB in the burning process;
- The NiO particles will also cause a reduction of combustion heat and the insurgence of regressing surface in fuel grains;
- More NiO (5 wt% < [NiO] ≦ 10 wt%) does not lead to a faster regression rate due to its inhibitory effects on combustion.

Conclusions

- NiO can intensely decrease the thermal stability of the HTPB matrix, and this catalytic effect is mainly reflected in the final pyrolysis stages of polybutadiene components;
- NiO also cause the reduction of combustion heat and the insurgence of surface phenomena while catalyzing the pyrolysis process, improving the thermal conductivity, and promoting the radiative heat transfer;
- Several factors lead to an optimal content, 5 wt%, corresponding to the regression rate increase of 19.4% and 13.7% at G_{ox} = 50 kg/m²s and 150 kg/m²s, respectively;
- NiO can be a suitable candidate for regression rate enhancement, especially in the HTPB/paraffin blends or other multi-additive composites in hybrid rocket propulsion.

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