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Propagation of combustion and thermal characteristics of magnetic Al@Fe_3O_4 metalstable intermatallic composite

Anqi Wang[1], Jingtian Liu[1], John Z. Wen[1*]
[1]Department of Mechanical and Mechatronics Engineering, University of Waterloo
200 University Ave W, Waterloo, ON N2L 3G1
*john.wen@uwaterloo.ca

Abstract

Metastable intermetallic composites (MICs) are an interesting kind of material that provides superior yet controllable combustion performance. Multiple physical and chemical properties, such as gas release, pressurization, heat generation, reaction mechanism, mechanical and other electromagnetic properties, can be finely tuned by changing the oxidizer, typically metal oxide, used in the composites. Specifically, the involvement of magnetic material as oxidizer, such as Fe_3O_4, offers tremendous application potential for this material. In this research, we present the combustion properties and heat transfer process during the combustion of a thin film consisting of a novelly designed and fabricated core-shell structured Al@Fe_3O_4 nanoparticles. The Al@Fe_3O_4 nanostructure was fabricated using a bottom-up crystallization method that allows the sub-10-nm Fe_3O_4 nanoparticles to directly grow on the surface of aluminum nanoparticles, allowing the maximum direct contact between fuel and oxidizer, thus significantly accelerating the redox reaction of the material compared to randomly mixed Al/Fe_3O_4 nanocomposite. The combustion of a PVDF/HPMC/Al@Fe_3O_4 thin film was observed by using simultaneous visual and thermal high-speed recording systems consisting of a fast camera (10,000 fps), a high-speed infrared thermal camera (400 fps), and a two-color pyrometry system (4,000 fps). Unlike previously investigated polymer/Al@CuO thin film, where the burning particles were ejected from the thin film due to the gas generation from CuO and decomposition of polymers, the Al@Fe_3O_4 thin film remained intact during and after combustion, due to the gasless combustion nature of Fe_3O_4 and milder reactivity. The retention of the thin film structure allowed a clear definition of pre-heating zone, reaction zone, and post-combustion zone for the thin film during the reaction propagation. Numerical analysis was performed on the temperature results based on heat generation from chemical reaction and heat transfer from conduction, showing clearly how thermal processes governing the ignition, propagation, and cooling of the MICs during combustion. The maximum temperature of the thin film during combustion was found to be around 2200K, substantially lower than that of Al@CuO, while the preservation of the structure kept the reaction heat within the thin film, thus accelerating the combustion speed to over 10 cm/s, much higher than Al@CuO. The collected post-combustion thin film revealed the reaction mechanism of the combustion of Al@ Fe_3O_4. The magnetic properties of the Al@Fe_3O_4 nanocomposite also bring in scientific and applicational values, including preliminary investigations of delivery and combustion under the effect of magnetic field.