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Characterization of Nanothermite Material for Solid-Fuel Microthruster Applications

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Nanothermite composites containing metallic fuel and inorganic oxidizer have unique combustion properties that make them potentially useful for microthruster applications. The thrust-generating characteristics of copper oxide/aluminum nanothermites have been investigated. The mixture was tested in various quantities (9–38 mg) by pressing the material over a range of densities. The testing was done in two different types of thrust motors: one with no nozzle and one with a convergent–divergent nozzle. As the packing density was varied, it was found that the material exhibited two distinct impulse characteristics. At low packing pressure, the combustion was in the fast regime, and the resulting thrust forces were ∼75 N with a duration of less than 50 μs full width at half-maximum. At high density, the combustion was relatively slow and the thrust forces were 3–5 N with a duration 1.5–3 ms. In both regimes, the specific impulse generated by the material was 20–25 s. The specific impulse and short thrust duration created by this unique nanothermite material makes it promising for micropropulsion applications, in which space is limited.

I. Introduction

RECENT research has demonstrated that microthrusters can be designed to reliably create thrust impulses in the impulse ranges defined as microthrusters (∼10 μN to 10 N ranges) [1–7]. The fuels used in such systems include lead styphnate, glycidyl azide polymer composites, composites of double base (DB) and black powder (BP), BTATz, and DAATO3.5 [1–6]. A microthruster containing ∼7 mg of DB + 30%BP produced a measured thrust of 1 mN, a duration of 1.15 s, and total impulse of 1.13 mN · s [3]. Another recent work reported on a quartz thruster containing DAATO3.5 capable of producing 100 mN of peak thrust over a duration of ∼80 ms and a total impulse of ∼20 mN · s [1]. These propellants have combustion rates ranging from 5–100 mm/s. Another set of work has demonstrated thrusters using gunpowder-based propellants that produced up to 0.38 N of peak thrust in a duration of ∼0.4 ms [5].

Certain applications of solid-propellant microthrusters, such as course correction of high-velocity projectiles or microsatellites, require that the actuation time be as short as possible. For example, lateral guidance of spin-stabilized projectiles requires short-duration thrust to avoid rotation of the thrust vector as the projectile spins. Considering a projectile rotating at greater than 200 Hz, a thrust duration of 0.4 ms would correspond to a projectile rotation of ∼29 deg. For such applications, the fuel should be chosen to have the highest possible combustion rate, thereby minimizing movement of the thrust vector. However, the thrust fuel should not detonate, which would lead to damage of the projectile.

It was recently shown that the nanothermite composite consisting of CuO nanorods mixed with Al nanoparticles is capable of producing reaction propagation rates similar to those of conventional primary explosives, but with pressure levels well below that of solid explosives [8]. This characteristic makes the composite a promising candidate for fast-impulse microthruster applications. It was found that this nanothermite composite is capable of producing shock waves with Mach numbers up to 2.44 in an air-filled tube [8].

In this paper, the thrust performance of a nanothermite composite (CuO nanorods and Al nanoparticles) in a simple prototype thruster motor is presented. This composite was tested at a wide range of packing densities in a motor without any nozzle, as well as in a motor with a convergent–divergent nozzle.

II. Experimental

A. Nanothermite Preparation

The nanothermite composition consisted of CuO nanorods and Al nanoparticles. The CuO nanorods were synthesized using the surfactant templating process, described elsewhere [9]. The aluminum nanoparticles were purchased from Novacentrix, with an average diameter of 80 nm and an average Al_2O_3 shell thickness of 2.2 nm. First, a slurry was prepared by dispersing CuO nanorods in 2-propanol by sonication for 30 min. Then the aluminum nanoparticles were added to the slurry, and it was sonicated for 4 h. The sonication was carried out using a Cole-Parmer ultrasonic cleaning bath. After mixing, the slurry was dried in an oven at 90°C until all the 2-propanol was removed. The mixing ratio of the composite was 17:40 (Al:CuO) by weight. This ratio had been previously optimized for maximum combustion rate [9]. The optimized equivalence ratio will lead to the maximum conversion of the reactants into products.

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