NICKEL-COATED ALUMINUM PARTICLES: A PROMISING FUEL FOR MARS MISSIONS

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Combustion of metals in carbon dioxide is a promising source of energy for propulsion on Mars. This approach is based on the ability of some metals (e.g. Mg, Al) to burn in CO_2 atmosphere and suggests use of the Martian carbon dioxide as an oxidizer in jet or rocket engines [1, 2]. Analysis shows that CO_2/metal propulsion will reduce significantly the mass of propellant transported from Earth for long-range mobility on Mars and sample return missions. Recent calculations for the near-term missions indicate that a 200-kg ballistic hopper with CO_2/metal rocket engines and a CO_2 acquisition unit can perform 10-15 flights on Mars with the total range of 10-15 km, i.e. fulfill the exploration program typically assigned for a rover [3].

Magnesium is currently recognized as a candidate fuel for such engines owing to easy ignition and fast burning in CO_2 [1, 2, 4]. Aluminum may be more advantageous if a method for reducing its ignition temperature is found. Coating it by nickel is one such method. It is known that a thin nickel layer of nickel on the surface of aluminum particles can prevent their agglomeration and simultaneously facilitate their ignition, thus increasing the efficiency of aluminized propellants [5, 6].

Combustion of single Ni-coated Al particles in different gas environments (O_2, CO_2, air) was studied using electrodynamic levitation and laser ignition [7]. It was shown that the combustion mechanisms depend on the ambient atmosphere. Combustion in CO_2 (see Fig. 1) is characterized by the smaller size and lower brightness of flame than in O_2, and by phenomena such as micro-flashes and fragment ejection (see image 4). The size and brightness of flame gradually decrease as the particle burns.

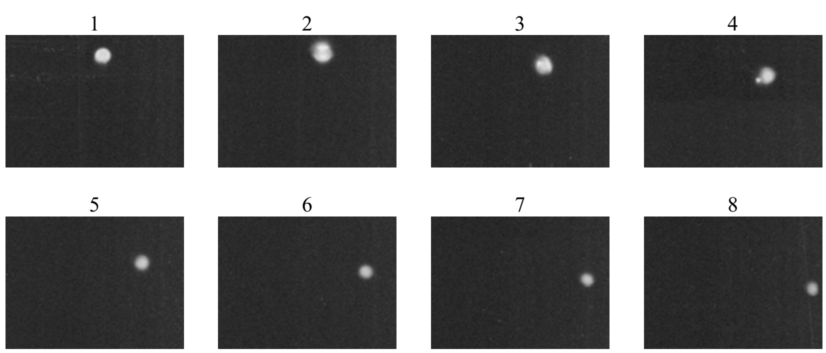

Figure 1: Combustion of Ni-clad Al particle in CO_2.
(0.5 μs between images, viewing area 1236 x 921 μm)

Remarkably, burning of Ni-clad Al particles in air (see Fig. 2) involves two stages, with inverse images of flame (bright core-dark flame and dark core-bright flame). Such images have never been observed in prior experiments with pure Al particles. Thus, we expect that this new phenomenon is caused by the presence of two elements (Al and Ni) in the particles.

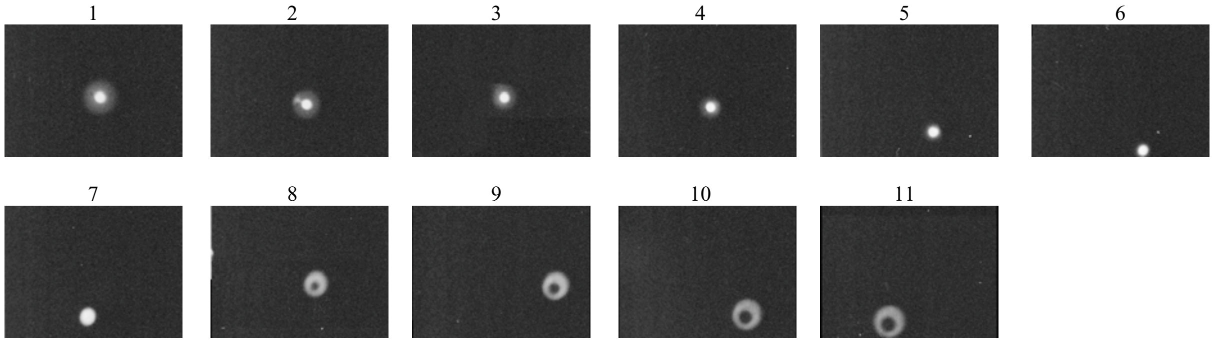

Figure 2: Combustion of Ni-clad Al particle in air.
(1.3 μs between images, viewing area 1236 x 921 μm)

Recent studies [8] show that the Ni coating dramatically decreases both the ignition delay time of laser-heated Al particles and the critical ignition temperature of gas-heated Al particles. Exothermic intermetallic reactions between liquid Al and solid Ni are considered as the main reason for the lowered ignition temperature of Ni-coated Al particles.

The detailed characterization of the process requires spatial and temporal resolutions that can be achieved only with relatively larger particles (1-5 mm). To avoid the natural convection and liquid flow effects, experiments on combustion of such particles will be conducted in microgravity environment using NASA research aircraft. The ignition and combustion will be studied by using high-speed and infra-red video cameras, and product composition analysis. Special attention will be devoted to elucidating the roles of inter-metal reaction and physical processes in surface layers (e.g. cracking of the shell, melt spreading).

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