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BURN RATE MEASUREMENTS OF NANOCOMPOSITE THERMITES

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ABSTRACT

Burn rates were experimentally determined for nanocomposite thermite powders composed of aluminum (Al) fuel and molybdenum tri-oxide (MoO_3) oxidizer under well-confined conditions. Confined pressures were also measured. Samples of three different fuel particle sizes (44, 80, and 121 nm) were analyzed to determine the influence of particle size on burn rate. Bulk powder density was varied from approximately 5 to 10 percent. The burn rates ranged from approximately 600 to 1000 m/s. Results indicate that burn rate increased with decreasing particle size, and the smallest particle composite also exhibited less variation in burn rate as the bulk density increased.

INTRODUCTION

A thermite reaction is a highly exothermic reaction between a metal and a metal or metallic oxide. When the fuel metal species is aluminum and the oxidizer is a metallic oxide (i.e., CuO_3, Fe_2O_3, MoO_3), the reaction temperature and heat of combustion can be excessively high such that the composite is ideal for ordinance applications. Thermite composites are of great interest in combustion studies, partially due to their practical applications ranging from igniters to incendiary devices. Wang et al. (1993) provide a thorough review of thermite reactions and discuss additional thermite applications.

Nanoscale aluminum particles are becoming more readily available and may provide a new opportunity to enhance the energy density and increase the burn rate of thermite reactions. Spherical particles of aluminum are considered nano-scale if the particle diameter is approximately 100 nm or less. Particles with other geometries are considered nano-scale if one or more of their major dimensions are less than 100 nm.

The two primary methods for the creation of nano-aluminum particles include gas phase synthesis and condensed phase synthesis. The methods involving gaseous precursors require an external energy source such as a flame, RF or DC plasma (Taylor and Vidal (1999) and Boulos (1985)). In the case of plasma synthesis, the particles are formed in the vapor phase at very high temperatures (>15,000K) and then rapidly quenched to the solid phase and collected. Thin-wire explosion can also be used to produce nano-scale particles, but the size-distribution of the particles is large relative to the other techniques. Vapor condensation methods appear to be the most successful methods to date for producing various metal nano-particles (Granquist and Buhrman, 1976). In this method, the metal vapors are condensed into a flowing stream of inert gas under reduced gas-pressures. Particle size is controlled by the flow and type of inert gas, total gas pressure, temperature of the evaporating metal, and the geometry of the vaporizing-condensing system. In this technique, particle nucleation and growth rates control particle size distributions (Puszynski, 2002).

Research has shown that increased burn rates can be achieved with smaller particle composites (Aumann, 1995). For example, Rugunanan and Brown (1994) showed that pyrotechnic burn rates decreased with increasing particle size of the constituents. In more recent work, Brown (1998) varied the particle size of the fuel species in the $Sb/KMnO_4$ system and found that reducing particle size from 14 to 2 microns increased the burning rate from 2-8 mm/s to 2-28 mm/s. These results suggest that reducing the fuel particle size to the nano-scale range may result in revolutionary burn rate performance.

This theory was further substantiated by Shimizu and Saitou (1990) in their evaluation of the effect of contact points on reaction rate. They found that in the Fe_2O_3-V_2O_5 system increasing the number of contact points between fuel and oxidizer particles increased reaction rates. In another study, Aumann et al. (1995) examined the oxidation behavior of aluminum nano-powders. They suggest that Al powder mixtures with average particle sizes of 20-50 nm can react 1000 times faster than conventional powdered thermites owing to