Reaction Rate and Ignition Temperature of Metal Particles in Various Oxidizing Media

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Abstract

Reactive metal particles are commonly added to fuels, propellants and explosives to increase their specific energy content. For example, currently there is considerable interest in the addition of metal particles to explosives to enhance their performance (e.g., blast pressure and impulse, work done by expanding products). To predict the performance enhancement of metallized explosives, information is needed on the ignition and combustion rates of the metal particles in various gaseous environments. This provides the motivation for the present study, which consists of a systematic investigation of the effect of particle material and size, and type of gaseous oxidizer on the reaction rates and ignition characteristics of various metal particles.

The ignition of a metal particle depends, in general, on the particle material, size, shape, surface characteristics, as well as the heating rate and the oxidizing atmosphere. In the present experiments, two thermal analysis techniques, thermogravimetric analysis (TGA) and discrete scanning calorimetry (DSC), are first used to extract the kinetic parameters associated with the oxidation rate of various metals. Two ASTM standard techniques are used to estimate the activation energy, one using the rate of mass gain with temperature (TGA) and the other based on the shift in peak heat release as a function of heating rate (DSC). Similar results are obtained with both techniques (e.g., for zirconium particles, activation energies of 171 kJ/mol and 174 kJ/mol, respectively, were obtained

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with the two techniques). The kinetic constants obtained using the thermal analysis techniques are then used together with conventional Frank-Kamenetski ignition theory to estimate ignition temperatures. To validate the predicted ignition temperatures, a novel apparatus is used which eliminates natural convection and produces well-defined heat losses. The particle under investigation is placed within a block of open cell silica-based aerogel. The aerogel is placed within a cylindrical tube furnace and an optical microscope is used to observe the point of ignition as the oven temperature is slowly increased. The reactive particles that are currently under investigation include magnesium, a magnesium/aluminum alloy, zirconium, and titanium. The oxidizing atmospheres consist of the gases CO_2, H_2O and air, as well as various mixtures of these gases, which simulate the combustion products of a high explosive. The results are consistent with the current understanding of the reaction mechanisms responsible for particle ignition. Thus for magnesium, ignition occurs near the melting point where the evaporation of magnesium becomes significant and the vapor phase magnesium-oxygen reaction is a leading mechanism of particle oxidation. In contrast, the ignition of zirconium particles occurs at temperatures considerably below the melting point and is dominated by heterogeneous surface reactions.