On the Statistics of Nanoaluminum Thermal Characterization and its Correlation with the Slow Oxidation/Combustion Parameters

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Tens of research articles and reviews describe the thermal behavior of spherical Al nanoparticles (*nAl*) of different diameter (from 10 to 200 nm) in different gases (Ar, He, N_2, air) under various heating rates (from 5 to 500 K/min) [1-3]. A very broad dataset representing the so-called 'reactivity parameters' (heat release over a certain temperature range, oxidation temperature onset, degree of oxidation up to certain temperature, oxidation rate, etc. [4]) has been obtained from easily available non-isothermal oxidation testing (DTA/DSC-TG-DTG). However, the thermal characteristics of *nAl* emerging from this dataset appears sometimes contradictory because of several reasons:

- the physical and chemical properties of the *nAl* itself, a metastable high-energy material (as many of the colloidal systems);
- the different production technology and storage conditions [5];
- the speculative and sometimes hazardous interpretation of the thermal data because of the poor characterization of *nAl* and lack of a complete information on nanoparticles characteristics.

A very ambitious goal of the thermal characterization of *nAl* would be to identify, if any, a correlation between its 'reactivity parameters' as provided by DTA/DSC-TG-DTG and the observed burning characteristics (ignition temperature, ignition delay, burning rate, specific impulse, etc.). Indeed some qualitative direct correlations between non-isothermal oxidation kinetic parameters (slow oxidation in weak oxidizers) and burning kinetics (fast oxidation in strong oxidizers) might exist. In this work an attempt is made to find such correlation based on the analysis of several published experimental datasets [6] and our own broad experimental database.

It is shown that processes occurring under *low-temperature oxidation* (before Al melting) might correlate with the composition of the passivation/coating layer of nanoparticles, their size distribution, and metal structure (for very fine particles, say ~10-30 nm). However, non-isothermal *high-temperature oxidation* (over 660ºC) and combustion of *nAl* appear to depend only on the initial particle size, cohesion degree, and active metal content while seem nearly independent from the initial passivating/coating layer of particles. The thermodynamic parameters of non-isothermal oxidation (oxidation enthalpy) for *nAl* could be compared only with the energetic characteristics of aluminized energetic materials formulation (such as burning enthalpy and I_s) but hardly correlate with the kinetic ones (such as burning rate).

1. M.M. Mench, K.K. Kuo, C.L. Yeh and Y.C. Lu. Comparison of Thermal Behavior of Regular and Ultra-Fine Aluminum Powders (Alex) Made from Plasma Explosion Process, *Comb. Sci. Tech.*, 1998, Vol. 135, pp. 269-292.
2. Y.S. Kwon, A.A. Gromov and A.P. Ilyin. Reactivity of Superfine Aluminum Powder Stabilized by Aluminum Diboride, *Comb. Flame*, 2002, Vol. 131, pp. 349–352.
3. S. Mohan, A. Ermoline and E.L. Dreizin. Pyrophoricity of Nano-Sized Aluminum Particles, *J. Nanopart. Res.,* 2012, Vol. 14, pp. 723(1-6).
4. A.A. Gromov, A.P. Ilyin, Y.S. Kwon, J.S. Moon and E.M. Popenko. Estimation of the Reactivity of Superfine Powders for Energetic Applications, *Comb. Sci. Tech.*, 2004, Vol. 176, pp. 277 – 288.
5. A.C. Reber and S.N. Khanna. Reactivity of Aluminum Cluster Anions with Water: Origins of Reactivity and Mechanisms for H_2 Release, *J. Phys. Chem. A*, 2010, Vol. 114, pp. 6071–6081.
6. M.L. Pantoya, S.W. Dean, The Influence of Alumina Passivation on Nano-Al/Teflon Reactions, *Therm. Acta*, 2009, Vol. 493, pp. 109–110.