Aluminum Nanocomposite Materials for Propellant Applications

S.W. Chung*, P.A. Jelliss*, S.W. Buckner*, G.J. Place*, J.M. Laktas*
*nanoMetallix LLC, 20 S Sarah St, St Louis, MO, 63108, greg@nanometallix.com

ABSTRACT

Aluminum is commonly used as an energetic additive in propellant and munitions formulations, providing performance improvements to a variety of processes. In this work, passivated aluminum nanocomposites are synthesized. Materials display enhancements to desirable characteristics for propellant applications, including weeks-long shelf life, the absence of an oxide layer, a small average diameter (below 20 nm), and high active aluminum content. Performance is subsequently augmented, as materials exhibit a significant increase in burn rate upon combustion. The advantages offered by such novel nanocomposties in conjunction with inherently scalable synthesis provides strong opportunity for commercialization and integration into conventional and novel propulsion systems.

Keywords: nanoaluminum, propellant, nanocomposite, nanoparticle, energetic

1 INTRODUCTION

Aluminum has high applicability in terms of energy release with one of the highest combustion enthalpies of all reactive metals. Thus, aluminum materials have been widely researched to develop propellant ingredients with high energy density. However, this high reactivity is also the source of aluminum's practical difficulties. Traditional research and production is focused on aluminum particles known to be reactive in ambient conditions and in water, thereby forming an oxide layer that limits the applied effectiveness, efficiency, and utility of such nanomaterials. Previous work describes the mechanism by which alumina coated composites combust (Figure 1), reporting strong inefficiency with regards to thermochemical and kinetic properties [1].

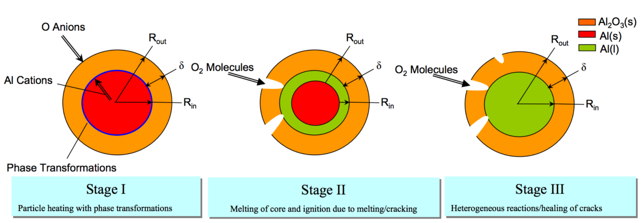

Figure 1. Combustion of alumina-coated particles [7]

A range of aluminum additives, from top-down manufacturing of micron-sized particles [2-4] to bottom-up chemical synthesis of aluminum composites on the nanoscale [5-7], have been shown to enhance the performance of solid propellants. Still, all previous solutions face one or more barriers to ubiquitous systems integration. Industry leaders and scientific pioneers have failed to produce aluminum nanoparticles with optimized combustion characteristics; conventional materials contain an oxide layer that minimizes energetic effects, are too large for complete and rapid combustion, and/or are not produced with scalable and cost-effective synthesis.

The reported subject matter reflects novel synthesis procedures and compositional enhancements developed to bypass traditional inadequacies and produce a material optimized for propulsion processes.

2 SYNTHESIS

Synthesis is performed with the use of a vacuum manifold and air-free, wet chemistry techniques. All solvents are distilled under argon, and all liquid reagents are degassed using a freeze-pump-thaw technique. Briefly, the precursor is dissolved in an organic solvent and converted to aluminum atoms. Then, a capping agent is added to the reaction mixture to passivate nanoscale aluminum particles. A catalyst is added to the mixture, then the reaction is stirred and allowed to proceed. Finally, the solvent is removed with the use of a vacuum, leaving a dry powder material [8-10].

3 CHARACTERIZATION

Materials are characterized using analysis procedures to describe morphology and composition. Particle size, phase transition and thermochemical characteristics, and compositional properties are reported.

3.1 DSC/TGA

Differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA) in Figure 2 reveals a large exothermic peak at ~300°C, while showing little to no endotherm at ~660°C, the melting point of aluminum. This reveals a revolutionary method of combustion that circumvents the traditional inefficiency of an oxide layer; the compound allows us to harness the energy of elemental aluminum for desired release. Moreover, ignition delays are reduced to achieve an unprecedented level of performance.

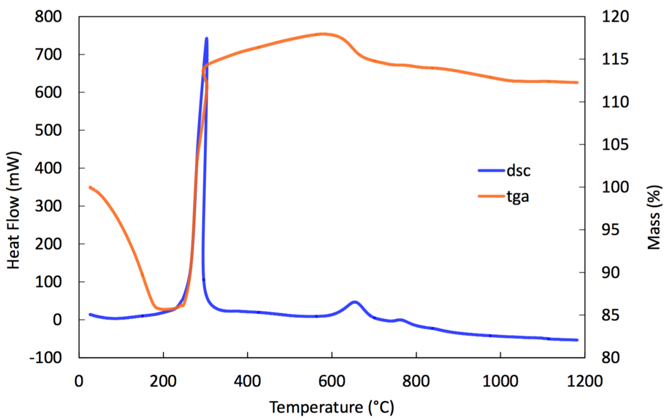

Figure 2. DSC/TGA analyses of nanoMetallix materials

3.3 PXRD

Powder X-ray diffraction (PXRD) analysis in Figure 3 reaffirms the observations shown by DSC/TGA analysis, revealing a high presence of face-centered cubic (FCC) crystalline aluminum.

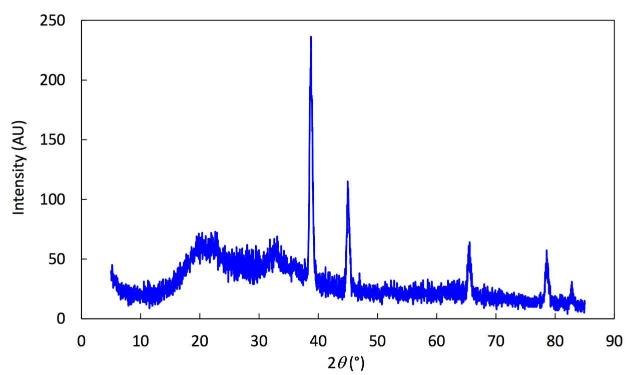

Figure 3. Powder X-ray diffraction (PXRD) analysis of nanoMetallix materials

Measurement of the Scherrer widths revealed aluminum particles are below 20 nm in diameter.

3.4 TEM

Verified via transmission electron microscopy (TEM), nanoparticles are produced below 20 nm in diameter, representing a decrease of 1-3 orders of magnitude when compared to competing materials. This reproducible decrease in size leads to increased surface area available for combustion and a subsequent increase in burn rate.

4 PERFORMANCE

The performance of synthesized nanocomposites is described, including ignitability, compatibility with leading formulations, and combustion characteristics.

4.1 Ignitability

Materials display exceptional air stability, maintaining ignitability wihtout pyrophoricity for weeks after exposure to ambient conditions. This vital characteristic implies a strong protection from oxidation, preserving high-performance capabilities for desired release.

4.2 Material Compatibility

Materials exhibit strong material compatibility when compounded with conventional propellant ingredients – hydroxyl-terminated polybutadiene binder (HTPB) and ammonium perchlorate (AP) oxidizer. Novel nanoaluminum composites were incorporated successfully at 0.5% by mass prior to burn rate testing.

4.3 Burn rate

Burn rate measurements gathered by a High Pressure Strand Burner at Texas A&M University's Turbomachinery Laboratory reveal a ~60% average increase (Figure 4) in burn rate over the leading commercial alternative - 100 nm oxide passivated nanoaluminum - when incorporated into a conventional HTPB/AP complex.

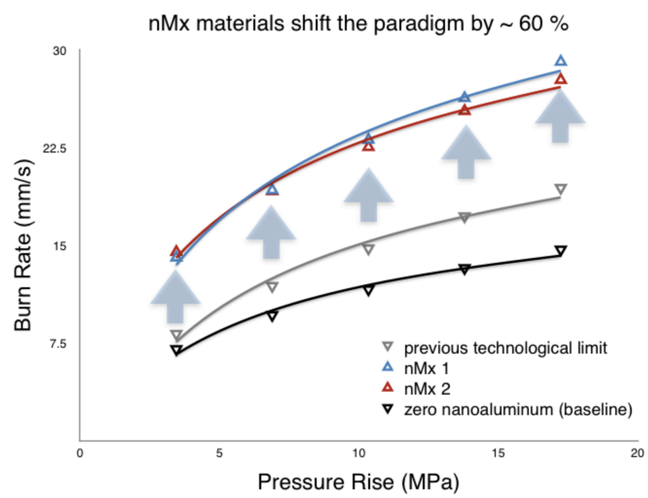

Figure 4. Burn rate comparing 2 nanoMetallix compounds to the highest-performing commercial nanoaluminum and a control

This combustion behavior leads to a rapid increase in temperature and gas expansion, resulting in more favorable combustion characteristics and a fuel with improved efficiency.

5 CONCLUSIONS

Synthesis procedures and material characterization and performance of novel aluminum nanocomposites are reported, revealing an enhancement of desirable propellant ingredient characteristics and proving the viability of inclusion into conventional formulations. Characterization reveals a strong enhancement in stability by the prevention of oxide layer formation, while performance analysis exhibits a significant improvement in burn rate and ignitability.

Low cost, scalable synthesis methods enable an opportunity for widespread market integration and utility. Current and future work aims to verify vital propellant characteristics and scale production to transfer the technology to market, such that it will improve the performance and handling characteristics of propellant delivered to missile systems and launch services.

Solutions will be of immediate applicability to all solid fuel formulations in weapons related technology within the Department of Defense, allowing for tailorable enhancements to device range, velocity, and effect by mere addition or substitution. Novel designs will subsequently be enabled by these solutions, allowing for smaller, more agile systems to deliver increased impact.

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