Development of a High Energy Double Base Propellant

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RESEARCH OBJECTIVES

Current double base propellants are limited in their performance and application due to limitations imposed by nitroglycerine migration and low physical strength. We aim to develop a new double base propellant based on the novel nitrate ester 1,4-dinitrato-2,3-dinitro-2,3bis(nitratomethylene) butane (SMX) which addresses these issues. Additionally, the high oxygen content of SMX provides the ability to include high-enthalpy additives to further increase performance. Through the use of fast-crash crystallization and melt-cast processes, we have developed a propellant using nitrocellulose, nanoaluminum, and SMX which is theoretically capable of delivering higher performance than existing double base propellants, with improved aging properties and similar sensitivity. The resulting propellant has been characterized using a variety of methods, including scanning electron and optical microscopy, BET surface area analysis, differential scanning calorimetry and thermogravimetric analysis, and safety testing using commonly accepted methods.

MATERIAL PROCESSING

Initially, SMX crystals (Fig. 1) are deposited on the surface of nitrocellulose fibers using a fast-crash process in a ternary solvent blend of ethanol, diethyl ether, and acetone. High-enthalpy fuels (e.g., aluminum) may be added at this point, if desired, to increase performance of the propellant. Following solvent removal, the material is thermally cycled to form a eutectic blend of SMX and nitrocellulose at the surface, entraining the aluminum nanoparticles in the process and ensuring their continued attachment and dispersion. The finished product is then pressed, melt-cast, or solvent-cast into the final desired propellant grain geometry; at 40 wt% loadings of SMX, the propellant exhibits high strength, with a Shore D hardness of 67.

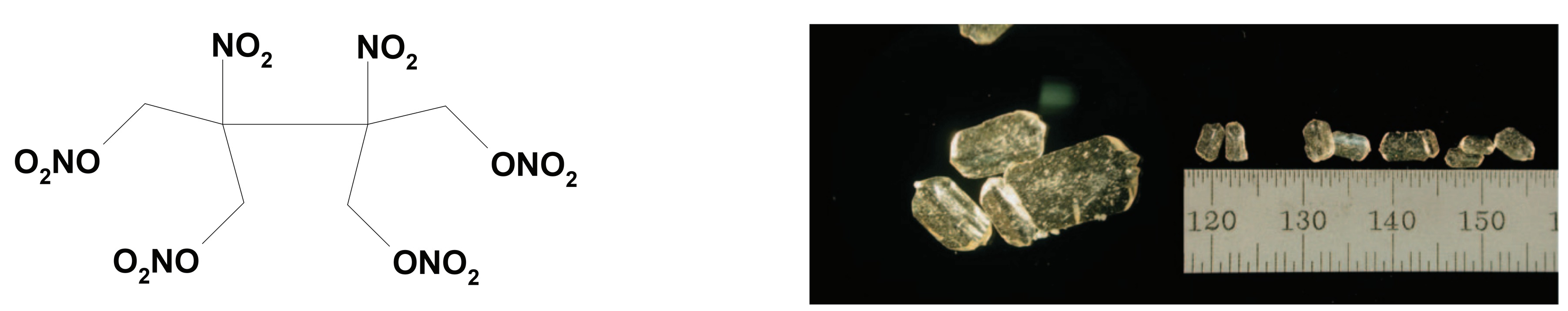

Figure 1: SMX molecular structure (left) and crystal appearance[1] (right).

PROPELLANT PERFORMANCE

The combination of SMX and nanoaluminum addition allows this propellant to theoretically outperform existing double base compounds (see Fig. 2) on the twin bases of combustion temperature and product ratio of specific heats. The reasons for this improvement are twofold: first, from the heat of formation contribution of alumium oxide, and second, from SMX, which we have measured Δh_f^o = -636.4 kJ/mol. Additionally, due to the room-temperature solid properties of SMX, it is possible to create formulations with significantly improved oxygen balance when compared to existing nitroglycerine-based propellants. Finally, the low vapor pressure of SMX portends well for its aging properties; this should lead to reduced migration in the propellant and a longer shelf life for fielded systems.

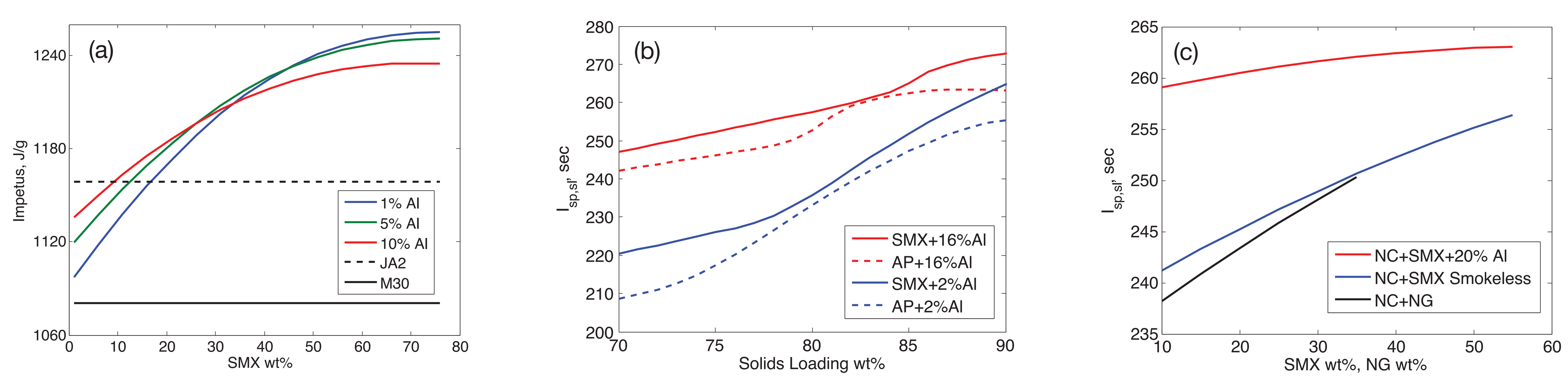

Figure 2: SMX propellant performance comparisons with (a) existing gun propellants, (b) composite rocket propellants, and (c) double base rocket propellants.

MATERIAL CHARACTERIZATION

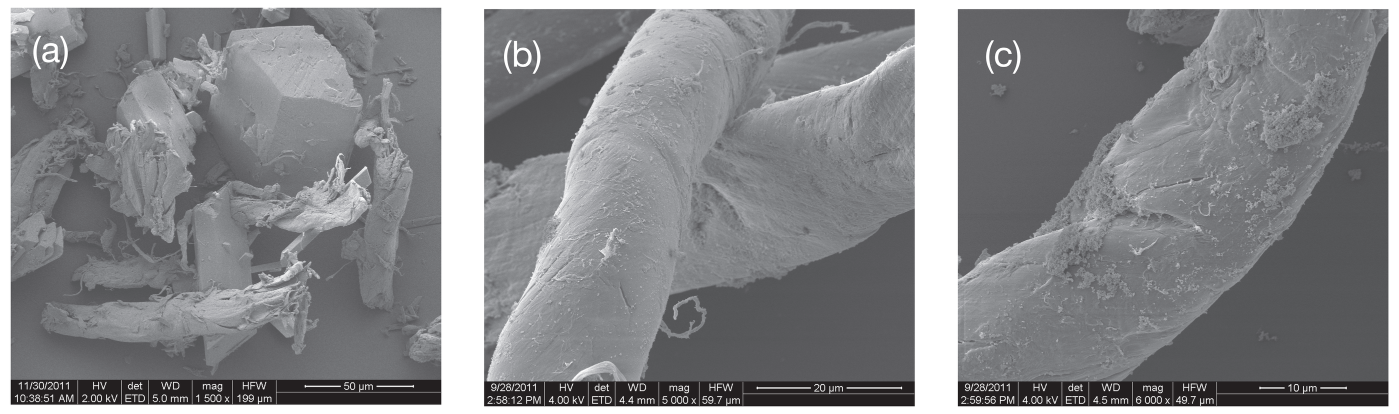

Figure 3: SEM imaging of (a) SMX crystals deposited on NC, (b) SMX+NC eutectic fibers, and (c) SMX+NC eutectic fibers with 80 nm nAl.

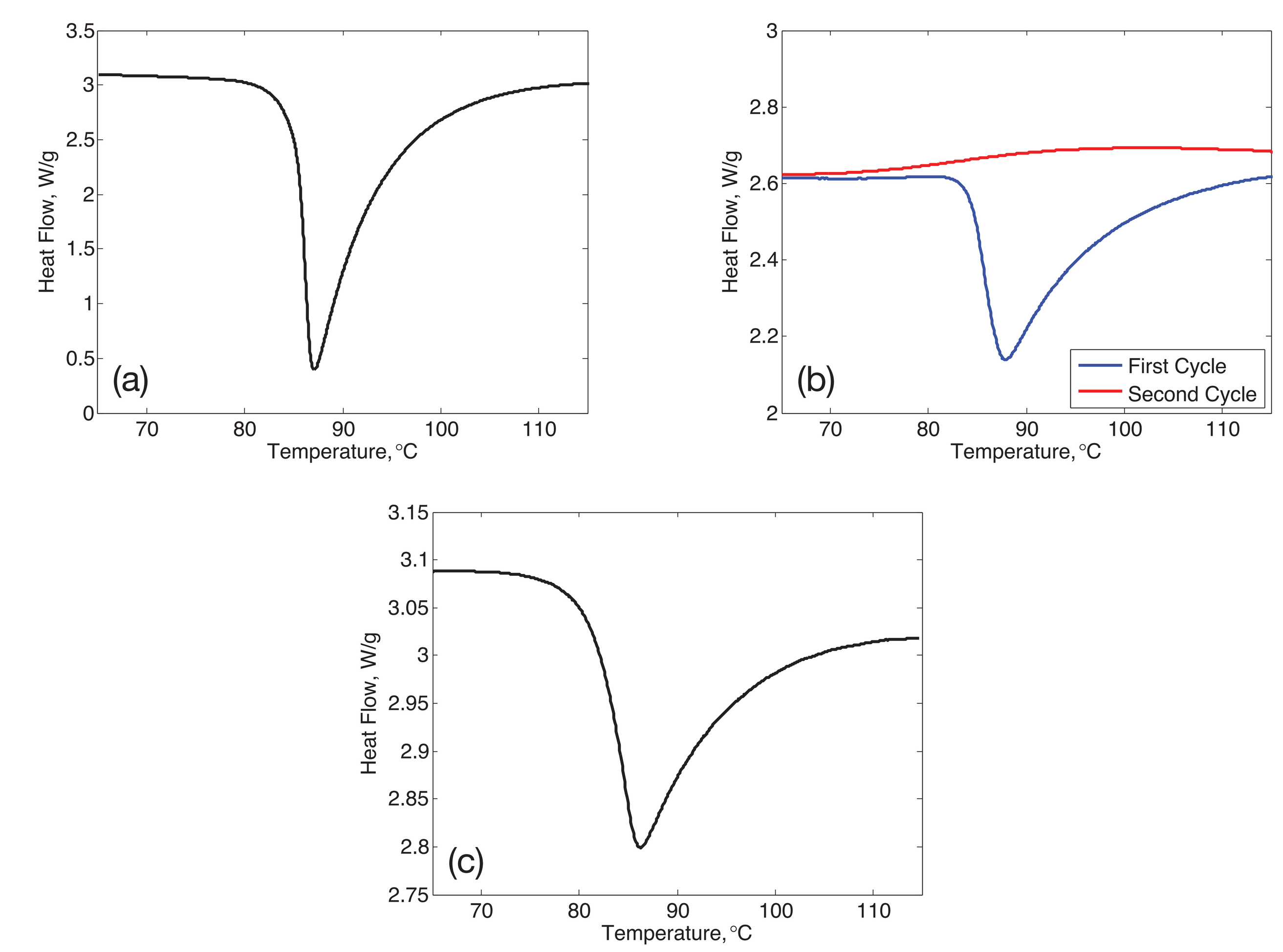

Figure 4: DSC thermograms of (a) neat SMX with melt endotherm at 85 °C, (b) SMX+NC formulation before and immediately after thermal cycling, and (c) SMX+NC formulation after thermal cycling and eutectic formation.

Propellant samples were examined using a variety of techniques to evaluate formulation properties and results of the mixing process. Scanning electron microscopy was conducted on both non-aluminized and aluminized versions of the propellant (Fig. 3), showing that a high quality dispersion of the 80 nm aluminum fuel particles is achieved using this process. Additionally, imaging conducted prior to and following the thermal cycle process revealed the disappearance of the SMX crystals, indicating potential formation of a eutectic mixture at the surface of the nitrocellulose fiber. This result was further supported by BET surface area analysis; material tested following thermal cycling exhibited a lower surface area than material tested prior to thermal cycling. Finally, differential scanning calorimetry was used to evaluate the propellant; prior to the thermal cycle process, a clear endotherm is present at the SMX melting point of 85 °C, while propellant tested after thermal cycling showed no endotherm at all (Fig. 4). Following a 48-hour solidifcation period, a new endotherm appeared at a reduced temperature of 81 °C, as is expected for eutectic mixtures.

SAFETY TESTING

Thus far, propellant samples have been subjected to drop weight impact, electrostatic discharge, and BAM friction testing, using go/no-go criteria and a Neyer D-Optimal statistical test method. Material was tested in a loose powder state prior to final compaction into propellant grains. The sensitivity to ignition via both electrostatic discharge and friction is similar to that of JA2, and significantly lower than neat baseline materials (e.g., PETN). Drop weight ignition events occurred at approximately 34% the height of JA2, but were localized, i.e., the reaction did not propagate completely throughout the tested material.

CONCLUSIONS & FUTURE WORK

SMX and nanoaluminum both appear to provide useful avenues for increasing the performance of double base propellant formulations. With its uniquely-placed melting point, SMX shows great promise as a replacement for nitroglycerine in double base propellants; though it is soft enough to be melt-cast and pressed, it remains a solid at room temperature, allowing higher loading and ensuing improved oxygen balance without penalty of grain softness. The next steps in development include combustion testing to evaluate flame structure and burning rate exponent, and evaluation of process scale-up to enable fielding of the finished product in a timely fashion.

Ref 1: Chavez, et al. Synthesis of an Energetic Nitrate Ester. Angew. Chem. (2008) vol. 120 (43) pp. 8431-8433

This project was funded by US Army ARDEC under contract W15QKN-11-C-0049.