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Burn Rate Sensitization of Solid Propellants Using a Nano-Titania Additive

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Introduction

Additives comprising fractions of a percent to several percent of solid propellant mixtures have been considered through the years and are commonly employed in many rocket propellants and explosives. Various additives include burn-rate modifiers (e.g., ferric oxide, metal oxides, and organometallics); curing agents; and plasticizers (Sutton and Biblarz 2001). In certain cases, additions of small (< 5% by weight) amounts of powdered material to the propellant mixture have been shown to increase or otherwise favorably modify the burn rate (Brill and Budenz 2000). For example, it has been observed by a few investigators that TiO_2 (titania) particles may enhance stability by creating burn rates that are insensitive to pressure over certain pressure ranges (Taylor 1996). It is suspected that other organometallic particles may produce these and other favorable traits (Brill and Budenz 2000). Nanoparticle additives may have an even further influence on the burn rate because of their high surface-to-volume ratios.

Over the past few years, nanoparticles of many different compounds and combinations have received considerable attention in the scientific and engineering research communities. This surge of activity is a result of the many favorable characteristics certain materials and applications exhibit when nanoparticles are involved in some fashion. Benefits are certainly seen in composite Al/AP/HTPB-based solid propellant formulations when the micron-scale metal fuel (i.e., Al) is replaced by nanoscale particles (Lessard et al., 2001; Dokhan et al., 2002). However, little research has been done on the effect of nanosized additives such as organometallics and related burn rate-enhancing and smoke-reducing compounds.

The present paper presents the results of a study wherein nano-sized titania (TiO_2) particles manufactured in the authors' laboratory were added to a high burn rate composite propellant mixture. Samples of this mixture were burned in a high-pressure bomb to determine its burn rate behavior compared to mixtures without the nanoparticles. Details on the experimental procedure for preparing the mixture are presented first, followed by the results of the burn rate experiments.

Experimental Procedure

Materials for the synthesis of the TiO_2 particles included Isopropanol anhydrous, 2,4-Pentane-dione, and Titanium isopropoxide purchased from Sigma Aldrich. Deionized (DI) water was also used. The procedure for the TiO_2 particles involved a sol-gel technique. This technique is based on the hydrolysis of liquid precursors and the formation of colloidal sols. Specifically, 100 ml of Isopropanol anhydrous and 2 ml of 2,4-Pentanedione were added together and stirred for 20 minutes. Titanium Isopropoxide was then added to the solution and stirred for 2 hours. DI water was then added for hydrolysis and stirred for an additional 2 hours, and the solution was left to age for 12 hours. This procedure produced a yield of 1.6 g of nanoparticles.

X-Ray Photoelectron Spectroscopy (XPS) was used to verify the chemical structure of the TiO_2 particles. The resulting XPS data confirm the formation of TiO_2 particles due to the 2p3 peak at 458.89 eV of binding energy (Fig. 1) according to typical peak formation for TiO_2. Transmission Electron Microscopy (TEM) (Philips Technai transmission electron microscope) was also used to study the size and distribution of the particles. The TEM results revealed nano-sized arrays of particles with diameters on the order of 10 nm with a narrow size distribution.

For the final propellant mixture, the amounts for each component consisted of the following by mass: the fuel (3-µm Al + titania additive) was 20%, the oxidizer (200-µm monomodal Ammonium Perchlorate, AP) was 67.5%, Fe_3O_2 was 0.5%, the R-45M binder (HTPB) was 10.5%, and the cure agent (MDI) was 1.5%. The TiO_2 additive was 2.0% of the fuel by mass, or 0.4% of the entire mixture.

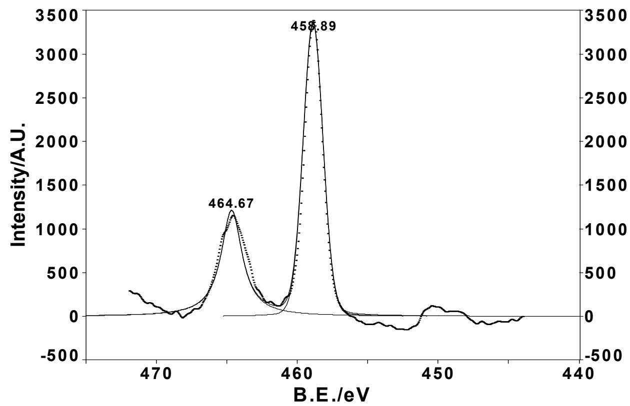

Figure 1. Deconvoluted Ti(2p) peaks obtained from nano-TiO_2 powder synthesized using the sol-gel technique.

The mixing procedure began by mixing all components into the mixer, starting with the HTPB followed by the Fe_3O_2, the aluminum powder, and the titania solution. The mixture was mixed for 20 minutes under a vacuum and then left under the vacuum until the solvent was completely evaporated (2 days). Heating tape was applied to the mixture to heat the mixing vessel to 50 °C to help evaporate the Isopropanol solvent from the titania solution. After all of the Isopropanol was evaporated, the AP was added, and the mixture was mixed under vacuum for 25 minutes. The MDI curing agent was added, and mixing continued for 5 minutes. The mixture was put under Nitrogen pressure at about 10 atm to compact the propellant for extruding. Teflon tubing with a 6.4-mm outer diameter was used to extrude the propellant samples from the mixture for burn testing. Several strands were extruded and left to cure for 2 days at room temperature.

A high-pressure strand burner was used to measure the burn rate of the propellant samples. Burn rates were determined from two different measurements: pressure and light emission. Both diagnostics provide information leading to the total burn time. The burn rates (cm/s) were calculated by dividing the measured length of each sample by the total burn time. Further details on the propellant mixing and burning apparatus and procedures are presented elsewhere (Carro et al., 2005; Arvanetes et al., 2005).

Results and Discussion

The propellant samples were burned in the strand burner at pressures ranging from 43 to 250 atm. Figure 2 presents the burn rate results of the present mixture containing the nano-Titania compared to the results of a baseline mixture from a separate study (Arvanetes et al., 2005) containing no additive (i.e., the entire fuel composition was Al). The mixture with the TiO_2 nanoparticles shows a significant increase in the burn rate as a function of pressure—almost a factor of ten over the range of pressures studied. This increase in the burn rate may come from the fact that titania nanoparticle additives greatly increase the surface area to volume ratio of the titania additive. In the present experiments, the titania nanoparticles seem to have acted as catalysts to the burning rate. Further study is required to determine the exact cause of the significant enhancement.

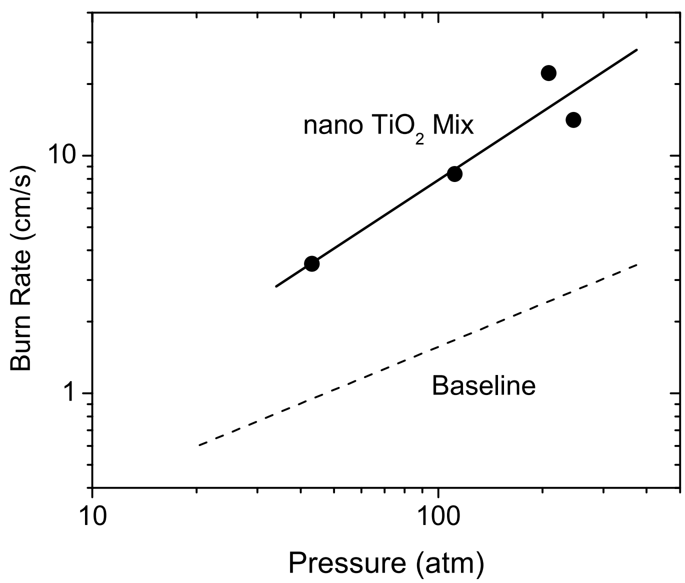

Figure 2. Burn rate results for nanoparticle titania additive and baseline mixture with no titania.

Conclusions

The results from this study confirm that the addition of titania nanoparticle additives at about 0.4% of the total propellant mass has a definite impact on the burn rate of solid propellants at various pressures. Future studies are required to further verify these results, including repetition of titania nanoparticle burns with larger pressure ranges, experimentation on the percentage of additive used in the propellant, consideration of other organometallic nanoparticle additives, conduction of new suspension methods of additives in various solvents, and exploration of structural characteristics and physical properties of the final product.

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