

Nano Additives and Plateau Burning Rates of Ammonium-Perchlorate-Based Composite Solid Propellants

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DOI: 10.2514/1.40831

Plateau propellants exhibit burning rate curves that do not follow the typical linear relationship between burning rate and pressure when plotted on a log–log scale, and because of this deviation, their burning behavior is classified as anomalous burning. This paper contains a literature review chronicling the last half-century of research to better understand the mechanisms that govern anomalous burning and to shed light on current research into plateau and related propellants. In addition to the review, a series of experiments investigating the use of nanoscale TiO₂-based additives in ammonium-perchlorate hydroxyl-terminated polybutadiene composite propellants was performed. The baseline propellant consisted of either 70 or 80% monomodal ammonium perchlorate (223 μm) and 30 or 20% binder composed of isophorone-diisocyanate-cured hydroxyl-terminated polybutadiene with Tepanol. Propellants were tested using a strand bomb between 3.45 and 17.24 MPa (34.0–170.1 atm). Analysis of the burning rate data shows that the crystal phase and synthesis method of the TiO₂ additive are influential to plateau tailoring and to the apparent effectiveness of the additive in altering the burning rate of the composite propellant. Some of the discrepancy in the literature regarding the effectiveness of TiO₂ as a tailoring additive may be due to differences in how the additive was produced. Doping the TiO₂ with small amounts of metallic elements (Al, Fe, or Gd) showed additional effects on the burning rate that depend on the doping material and the amount of the dopant. This work provides the first published propellant mixtures and burning rate results for composite propellants employing metal-doped nanoparticle additives.

I. Introduction

THE ability to tailor the burning rate of solid propellants has been a main driving force within the industry ever since it was determined that propellant burning rate can be modified through alterations to the propellant formula and/or through the use of various additives. During steady-state operations, traditional propellants follow a direct relationship between burning rate and pressure (only when plotted on a log–log graph) so that as one increases, so does the other. However, there are some propellant formulas that provide a distinct step away from this linear behavior and enable much more exotic relationships with pressure. This alternative class of propellant was first coined as having an anomalous-burning behavior because of the way the propellant burning rates departed from the norm. One of the more prominent versions of these anomalous-burning rates is known as plateau burning; this type of burning rate curve is the most common version of nonlinear relationships in modern propellants. A propellant that exhibits plateau burning has a pressure region in which the burning rate stabilizes and remains nearly independent of changes in pressure. Outside of this plateau region, the logarithm of

the burning rate has a typical linear relationship with the logarithm of the pressure.

This study was designed to fulfill two objectives: first, to provide an extensive literature review on works that have contributed to understanding or creating plateau-burning curves, and second, to investigate the use of nanoscale additives in propellants that exhibit plateau burning. Only steady-state operations of composite propellants were considered in these objectives.

II. Background

The direct study of anomalous-burning composite propellants has been an ongoing research topic for nearly half a century. The mechanisms responsible for the anomalous-burning rates can be divided into three categories: binder melt layer, oxidizer behavior, and additive influences. This literature review looks at these three parameters in a historical approach following works that contributed to the observation and understanding of anomalous-burning rates. The present review is the first to provide an inclusive look at the groups and individuals that contributed to anomalous burning and to, in turn, discuss each group's or individual's specific contribution and related work. In effect, this is the first publication that shows the evolution of the mechanism(s) controlling anomalous burning and allows insights and interpretations of earlier work that was not possible at the time. It is also the desire of the authors that readers can use this summary to draw their own thoughts and focus new research within the subject. With regard to the authors' own work, such a review was needed so that their work on burning-rate-tailoring additives could be put into perspective relative to established observations of anomalous burning.

A. Binder Melt Layer

One of the earliest groups to publish on the phenomenon of plateau burning within composite propellants was the work done by Steinz et al. [1] at Princeton University throughout the 1960s. While working on an early one-dimensional model for composite

Presented as Paper 4790 at the 44th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, Hartford, CT, 21–23 July 2008; received 5 September 2008; revision received 31 March 2009; accepted for publication 19 April 2009. Copyright © 2009 by the authors. Published by the American Institute of Aeronautics and Astronautics, Inc., with permission. Copies of this paper may be made for personal or internal use, on condition that the copier pay the \$10.00 per-copy fee to the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923; include the code 0748-4658/09 and \$10.00 in correspondence with the CCC.

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