Plateau Region Burning Dynamics of Composite Solid Rocket Propellants

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Abstract

In this paper, a series of experiments is presented that characterize the transient behavior in the plateau region of several ammonia perchlorate composite propellants. The instantaneous propellant burning rate is measured using an ultrasonic echo-location technique developed at the University of Illinois over the last few years. Two series of tests were conducted. One series involved rapid, monotonic changes in pressure in the vicinity of the plateau region of the burning rate curve. By varying the pressurization rate, different amounts of burning rate overshoot can be observed in this region. The second series of tests consisted of measuring the burning rate response of the propellant during oscillatory pressure perturbations which are less than ten percent of the mean chamber pressure. The information provided by these experiments can be used to determine the characteristic time scales of the processes responsible for the plateau, and to verify transient burning rate models which are valid in the plateau region. These data also provide information about the burning rate dynamics of this region, providing key insights into the mechanisms behind it.

Background

Solid rocket propellants typically exhibit increased burning rate with increasing pressure. Empirical burning rate data can often be fit to the Vieille's or St. Robert's burning rate law $\dot{r} = a\,p^n$, where $\dot{r}$ is burning rate, a is a constant, p is pressure, and n is another constant called the burning rate exponent. Some propellants exhibit pressure ranges where the burning rate is constant with pressure ($n \approx 0$), or decreases with increasing pressure ($n < 0$). These regions are referred to as burning rate plateaus.

Certain ammonium perchlorate – hydroxy-terminated poly-butadiene (AP-HTPB) propellants exhibit burning rate plateaus. A rocket operating in a plateau region of the burning rate curve is much less sensitive to pressure fluctuations that occur during the normal course of operation, making propellants that exhibit this characteristic highly desirable to rocket designers. The mechanisms that cause the plateau behavior are not well understood, although there is speculation that they are caused by the binder melt layer interfering with the burning of fine AP particles [1]. Even less information is available about how the burning rate in these regions responds to transient pressure perturbations, an issue which has implications concerning the stability of the solid rocket motor. Classical transient burning rate theory (e.g. [2] and [3]) predicts that the burning rate response to small, oscillatory pressure perturbations is nearly proportional to the burning rate exponent. In other words, the propellant response in the plateau regions, where the pressure exponent is zero, should be nearly non-existent. It has been observed that this is not the case. Until a better understanding of the physics of the plateau region is attained, *a priori* prediction of the effects of formulation changes on steady state and transient burning rates will not be possible.

Summary

This paper presents data from a series of experiments which were performed to investigate the dynamics of the plateau region in several AP-HTPB composite propellants. The transient burning rate of the propellant using an ultrasound echolocation system [4] during changes in pressure.

The experiments involved two series of tests. The first series involved subjecting a piece of propellant burning at steady-state to a rapid, monotonic change in pressure. Data from one such test, in which the pressure transient carries the burning rate into the plateau region, is shown in Figures 1 and 2. One can clearly see from this test that the processes responsible for the plateau region are too slow to follow the transient. Thus, the burning rate overshoots the plateau. By varying the pressurization rate, characteristic time scales of the processes that create the plateau region can be determined.

These tests are supplemented with a second series of tests, in which propellant burning in the plateau region is subjected to an oscillatory pressure perturbation. Burning rate measured during these tests is used to calculate the pressure coupled burning rate response of the propellant. These data also contain information about the time scales of the plateau region physics. Moreover, they can be compared to the data from the first series of tests to look at “linear” (small perturbation) versus “nonlinear” (large perturbation) effects.

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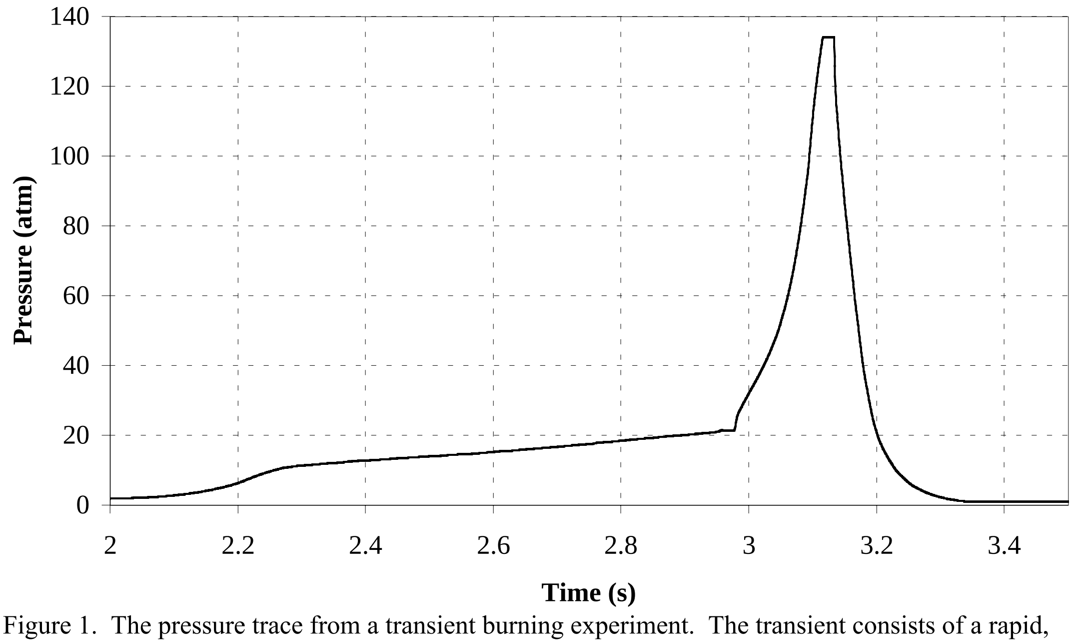

Figure 1. The pressure trace from a transient burning experiment. The transient consists of a rapid, monotonic pressure rise beginning approximately three seconds into the experiment.

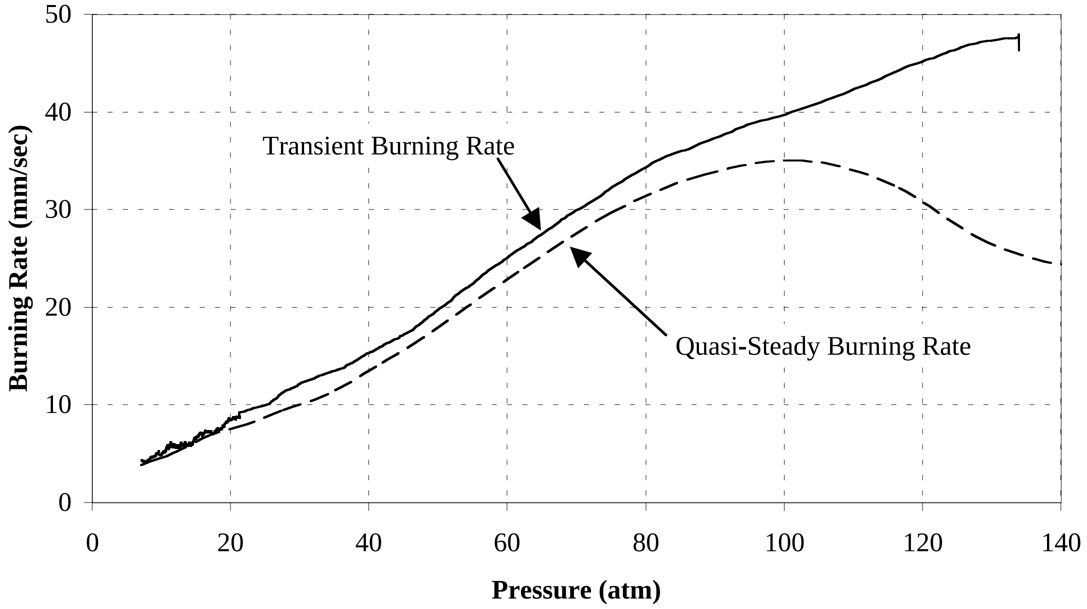

Figure 2. Burning rate from the transient experiment shown in Figure 1. The quasi-steady burning rate corresponds to the burning rate of this propellant under a steady-state pressure. The transient burning rate overshoots the quasi-steady curve as the chamber pressure moves rapidly into the plateau region.