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TITLE A STUDY ON THE CONTRIBUTION OF SLOW REACTION IN DETONATION

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A STUDY ON THE CONTRIBUTION OF SLOW REACTION IN DETONATION

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Interface velocimetry and plate push experiments of the TATB-based explosives investigated so far show the presence of nonsteady detonation; namely, the initial velocity history increases with increasing explosive charge length, a condition generally attributed to the variation of effective CJ pressure. A multistage reaction model is used to simulate these experiments. For these explosives, we find that the reaction must include a slow process stage so that the numerical results can be brought into good agreement with experimental observation.

1. INTRODUCTION

It is known that in cylinder tests the initial motion of the metal tube is very sensitive to the Chapman-Jouguet (CJ) pressure used for calculation;[1] and also that the equation of state (EOS) calibrated based on the cylinder test cannot be applied to another system in general. The problem can be demonstrated by the inability of the same EOS to predict plate push experiments.[2] This dilemma leads us to conclude falsely that there is no universally acceptable EOS for a particular high explosive (HE), and thus forces designers to manipulate the EOS to fit the emperical result instead of making predictions. The difficulty, we believe, is not entirely from the EOS, but rather from the simplification we make of the reaction process in detonation.

It has been observed that some explosives exhibit nonideal or nonsteady detonation behavior, showing increasing CJ pressure with respect to increasing HE charge length, contrary to the simple detonation theory with unique CJ pressure.[3] This condition arises from the presence of an extended reaction zone, the consequence of slow reaction (or delayed energy release) found in some HE. The presence of a long time scale in reaction provides the opportunity for more intimate interaction between reaction and hydrodynamics and therefore the effect of detonation is more sensitive to the system configuration. This sensitivity explains why we have to fudge the EOS to reflect such a condition for different applications when we use programmed burn, in which a constant detonation velocity is used to construct a burn map in the HE region and the reaction rate is determined by the sweeping speed of the detonation wave. For some HE, the origin of the slow reaction process is believed to be caused by solid carbon coagulation.[4] In the presence of a slow process near the end of reaction, the apparent CJ pressure reflects the condition of the partially reacted (although almost completed) state of the explosives rather than the final product. This paper shows the significance of the slow reaction in contributing to the overall detonation behavior as demonstrated in two types of experiments and related simulations.

2. MODELING INTERFACE AND PLATE PUSH EXPERIMENTS

A unified reaction model for initiation and detonation of heterogeneous high explosives has recently been developed,[5] replacing an *ad hoc* time-switching technique reported previously .[6] Using the model, we can obtain the reaction rate for detonation as a limiting case because both the hot-spot process time and the effective energy transfer time are much shorter than the slow process time. The total reaction fraction λ is therefore

$$\lambda = (1-\psi) + \psi\lambda_s, \tag{1}$$

with

$$\frac{d\lambda_s}{dt} = \frac{1}{\tau_s}(1-\lambda_s); \tag{2}$$

where λ_s represents the reaction fraction of the slow process, ψ the mass fraction of the explosive going through the slow process, and τ_s the slow process time. Both ψ and τ_s are taken constant. In the absence of slow process, ψ is set to zero. For calculation, however, the complete rate equations given in Ref. 5 are actually used; and Eqs. (1) and (2) represent only the asymptotic characteristics of the complete rate relations in detonation condition.

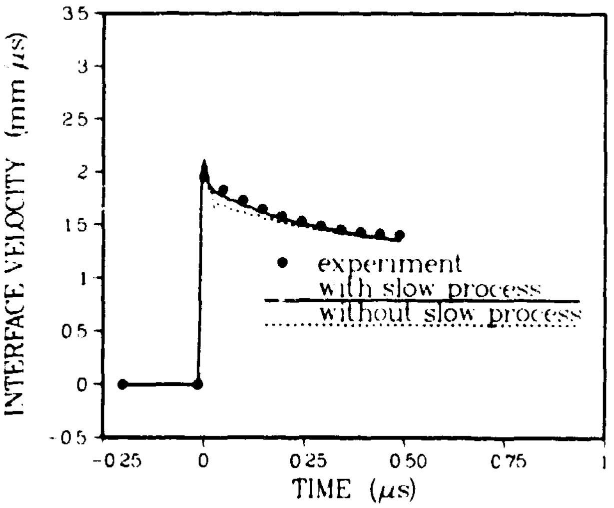

FIGURE 1
Interface velocity between 13-mm PBX-9502 and LiF window.

Experiments were reported using Fabry-Perot interferometry to measure interface velocity between explosive and transparent window.[7] The experimental system consists of a plane-wave lens (P-40), 25 mm of Composition B, a layer of 10-mm aluminum, the test high explosive, 0.013-mm aluminum laser reflector, and the transparent window (see Fig. 3 of Ref. 5). The results show increasing initial interface velocity history with increasing explosive charge length for PBX-9502 (95% TATB, 5% Kel-F), X-0407 (70% TATB, 25% PETN, 5% Kel-F), and pure TATB, indicating some sort of nonsteady behavior. To illustrate the effect of the slow process in detonation, calculations using $\psi = 0.15$ and $\tau_s = 75$ ns can reproduce the experimental results.[5,6] Additional evidence to support the presence of slow reaction using lithium fluoride (LiF) window is given in Figs. 1 and 2 for 13- and 25-mm PBX-9502. Calculations without the slow process are also presented in the above figures. The improvement of the simulations with slow process over those without is quite striking. The second set of experiments is plate push, using similar experimental setup as in the interface experiment, except that the aluminum shim and the transparent window are replaced by a thin metal plate (see Fig. 3). The metal surface velocity is measured and also calculated using identical parameters for the interface velocity simulation. Figures 4 and 5 show the results of 13- and 50-mm PBX-9502 pushing 0.5-mm aluminum

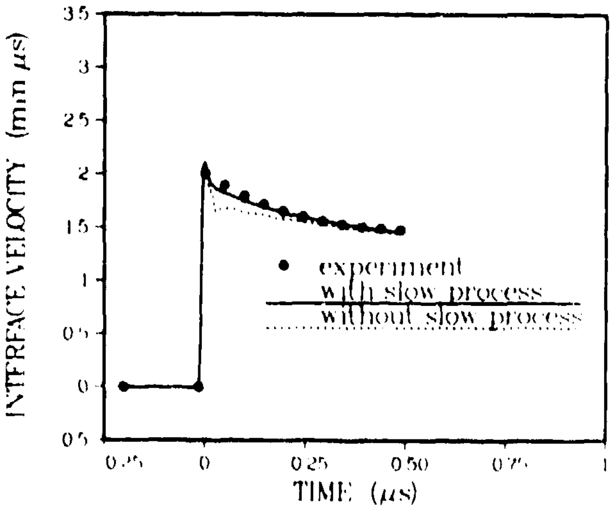

FIGURE 2
Interface velocity between 25-mm PBX-9502 and LiF window.

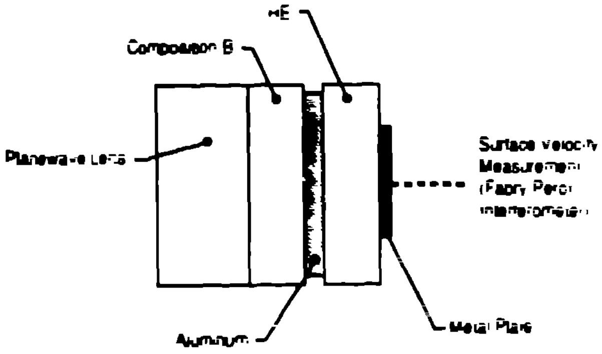

FIGURE 3
Plate push experiment

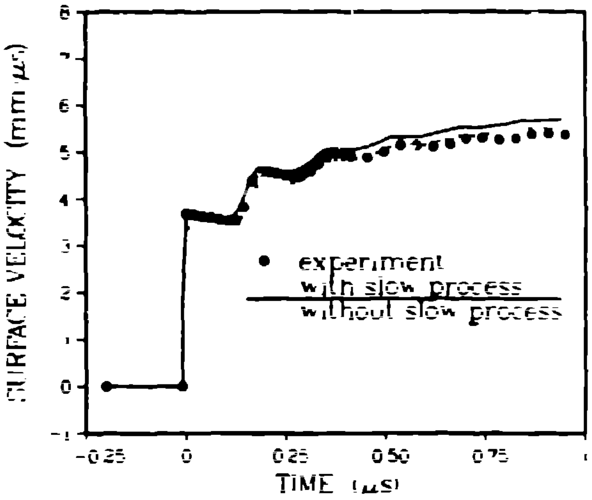

FIGURE 5
Surface velocity, 50-mm PBX-9502 pushing 0.5-mm aluminum plate

plates. Again simulations with the inclusion of slow process match the experiments much better, particularly in the earlier phase and for the thicker explosive charge case. Here we see a slight overestimate of the surface velocity in later time. The reason is probably due to the product component in the HOM EOS used.[8] The advantage of the HOM EOS is that it can be obtained independently, but it is usually more energetic than other types of EOS in the low pressure region, and the thin aluminum plate cannot hold up the pressure for long after a few reverberations. The calculations of 13- and 50-mm PBX-9502 pushing 0.56- and 0.46-mm tantalum plates respectively duplicate the experiments

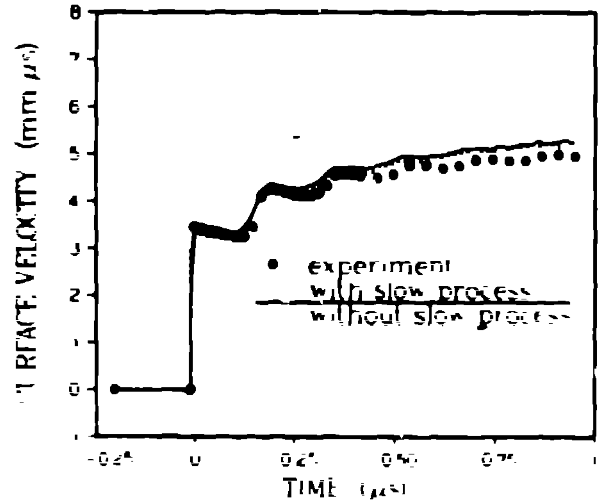

FIGURE 4
Surface velocity, 13-mm PBX-9502 pushing 0.5-mm aluminum plate

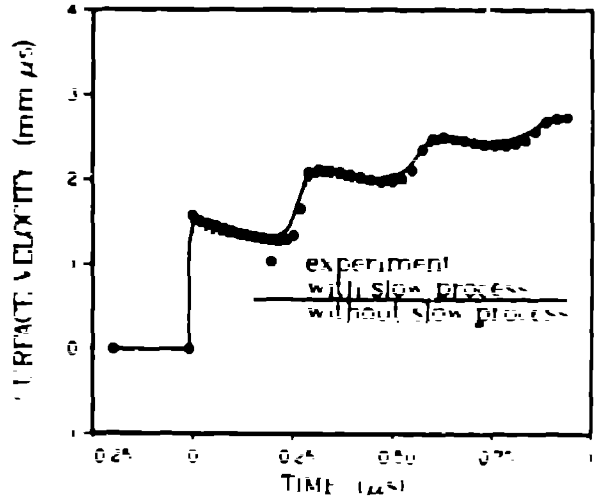

FIGURE 6
Surface velocity, 13-mm PBX-9502 pushing 0.56-mm tantalum plate

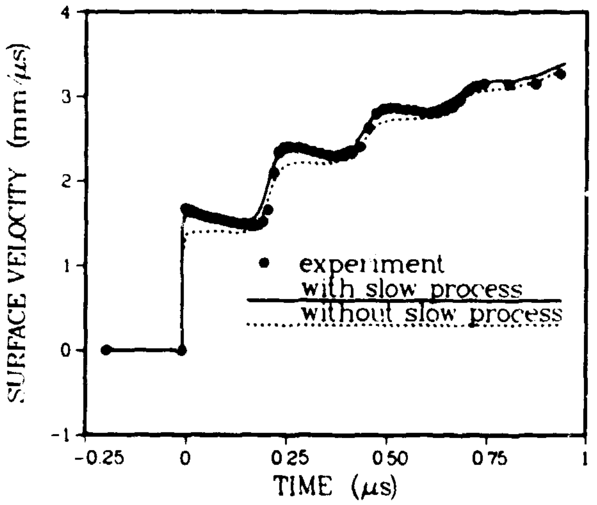

FIGURE 7
Surface velocity, 50-mm PBX-9502 pushing 0.46-mm tantalum plate.

much better even at late time, as shown in Figs. 6 and 7. Since tantalum has much higher density than aluminum and can maintain the high level of pressure longer, the behavior of the EOS is expected to be more accurate, justifying the contention we have made earlier on the aluminum plate result.

3. CONCLUSIONS

Without resorting to the manipulation of the EOS, we are able to simulate two types of experiments showing nonideal detonation behavior and we conclude that the phenomenon is caused in detonation by the presence of a slow process near the end of the reaction. In combining with the initiation stage, the unified reaction model has been validated further in different configurations, and should be a useful tool for many applications.

ACKNOWLEDGMENTS

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