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PROMPT REACTION OF ALUMINUM IN DETONATING EXPLOSIVES

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Abstract. The potential of aluminum (Al) reaction to boost detonation energy has been studied for decades, most recently spurred by the availability of nanometer-sized particles. A literature review is consistent with results from the small-scale shock reactivity test (SSRT). In this test, <1/2-g samples in confinement are shock loaded on one end, and the output at the other end dents a soft witness block. For samples in which 0.3 g of cyclotetramethylenetetranitramine (HMX) was mixed with 8 μm Al, the deepest dent occurred at 15% Al. When ammonium perchlorate (AP) was mixed with the same Al, the increased dents were consistent with changes in detonation velocity previously reported on similar mixtures. One outcome of this study is a new interpretation for the participation of Al in large scale gap tests on plastic-bonded explosives, which was discussed by Bernecker at this meeting in 1987.

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INTRODUCTION

The consensus in the literature is that Al at least partially reacts within the detonation zone of pure explosives, increasing both detonation velocity (D) and pressure, but is delayed in explosives with binders. Al reaction forms a solid product, thereby reducing the moles of gas products, but has such high thermal energy that it contributes to pressure by heating the gas products.

Price et al. [1] used an equation attributed to Kamlet for D that is proportional to the ¼ power of the product of gas moles/mass of explosive, heat of reaction, and mass fraction of gas products. This assumes reaction occurs within the detonation zone, which is referred to as ideal conditions. Figure 11 of reference 1 shows for beds of AP and Al packed at 55% of theoretical maximum density (TMD) that D peaks at ~15 %weight (%wt) Al according to the equation and at ~10 %wt in experiments on 95/5, 90/10, and 85/15 mixtures of 7-9 μm AP and 7 μm Al. Measurements were made at various charge diameters and extrapolated to infinite diameter so that they approached the ideal conditions in the calculations. The figure also shows that the measurements for D are less than the calculations as %wt Al increases. In similar measurements [2] for trinitrotoluene (TNT) mixtures at TMD, there was no effect for up to 32.2 %wt Al with large particle size (δ), <149 μm, whereas adding NaCl depresses D. This indicates that the increased energy from reacting some of the Al compensates for the dilution by the rest.

Tao et al. [3] studied the prompt reaction of both pentaerythritol tetranitrate (PETN) and TNT when mixed with 5 to 20 %wt of either 5 or 18 μm spherical Al. With PETN, both particle sizes of Al reacted within 1.5 μs, increasing the prompt energy release by 18 to 22% compared to PETN alone. With TNT, 5 to 10 %wt of 5 μm Al reacts promptly, while 10 %wt of 18 μm Al may not.

Including binders, however, inhibits Al reaction. Finger et al. [4] showed in cylinder expansion tests on mixtures of 85/15 HMX/Viton

with up to 15 %volume (%vol) of 5 μm Al that Al reaction began contributing to wall energy 4 μs after the detonation zone. In the plate dent tests of Smith [5], replacing some of the Kel-F with 2 to 20 μm atomized Al or 1 to 3 μm Al in mixtures with cyclotrimethylenetrinitramine (RDX) did not affect dent depth over the range of 65 to 92 %vol RDX. At ~65 %vol RDX, a sample with flake (400 mesh) Al had a somewhat deeper dent, while a sample with an inert mix of LiF and BaF_2 had a somewhat shallower dent.

Nanometer-sized Al did not increase its reactivity in the detonation zone. Brousseau et al. [6] measured D for TNT, Composition B, HMX-based plastic-bonded explosives (PBXs), and ammonium nitrate/fuel oil (ANFO) with both micron-sized and nanometric Al. D was increased when nanometric Al was mixed with TNT but declined when mixed in Comp B, PBXs (even those with energetic binders), and ANFO. Lefrancois et al. [7] showed in cylinder tests no significant change in D for mixtures of RDX, AP, Al, and wax with 100 nm versus 5 μm Al.

SMALL-SCALE EXPERIMENTS

The small-scale shock reactivity test (SSRT) measures the propensity of energetic materials to react within a microsecond timeframe from a strong shock, even for samples whose size is smaller than their critical diameter (d_c) for propagating steady detonation. The arrangement shown in Fig. 1 has a mild steel block with a central hole in which fits a RISI RP-80 detonator, an optional polymethyl methacrylate (PMMA) shock attenuator, and a 6.35-mm long sample. The downstream end of the sample contacts a soft Al witness block, which is dented by the combined shock from the detonator and sample reaction. All of the tests described in this report were without a PMMA gap so that the full output of the detonator is applied to the sample, thereby simulating a small volume of explosive within a detonating charge. The SSRT was characterized with various HMX mixtures, which provided a basis for comparison with results from a range of explosives [8].

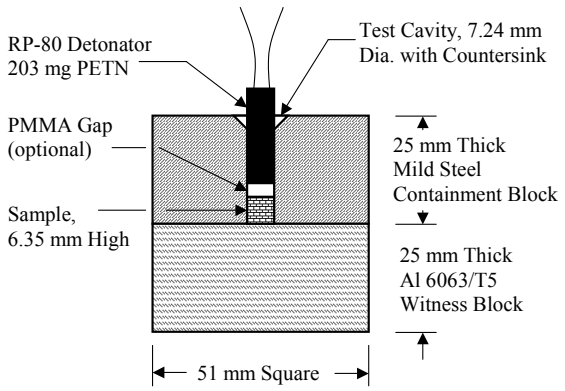

Figure 1. SSRT test arrangement.

Various amounts of Valimet H-5 Al with $\delta = 8$ μm and inerts were blended into samples that were consistently 60 %vol of Class 1 HMX (~298 mg) or 200 μm AP (~308 mg). Most samples were porous beds (without liquid) so that the hot HMX or AP reaction products had direct contact with the additive. These results are plotted in Fig. 2 relative to %wt of additive in the total solid (additive plus HMX or AP), which does not include the liquid for hand mixes.

When adding Al to porous HMX, the dent increased to a peak at 15 %wt Al and then slowly decreased, but was still greater at 25 than at 10 %wt Al. An opposite but much smaller effect occurred from adding melamine and glass beads to porous HMX, and when HMX/glass blends were mixed with hydroxy-terminated polybutadiene (HTPB) to fill the voids. For these various inert additions, the dent decreased by the same amount as the solid additive increased.

HMX/HTPB without any Al produced a slightly higher dent than the HMX by itself; although, the difference is within the ±0.1 mm repeatability for the test. With a 90/10 HMX/Al blend hand mixed with HTPB, the dent depth decreased by the same amount as when blending inerts with HMX. When a 80/20 HMX/Al blend was mixed with HTPB, the dent depth no longer decreased as for the inert additives, with or without HTPB, but was about the same as with no added Al. This indicates a small amount of Al reaction compensating for a primarily inert effect. The increased amount of Al in this mix is offset by less

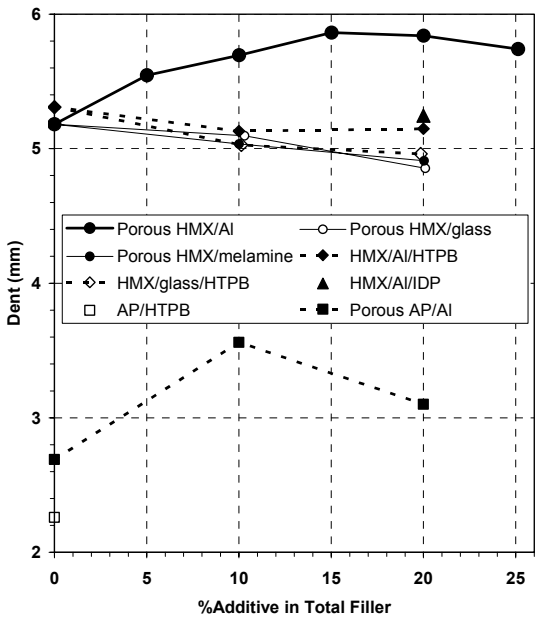

FIGURE 2. Effects of adding Al versus inerts and fuels to 60 %vol HMX or to 60 %vol AP.

HTPB. Since the 29 %vol HTPB is about the lower limit for a successful hand mix and poor mixing could promote Al reaction, the HTPB was replaced with the lower viscosity isodecyl pelargonate (IDP), a common plasticizer for HTPB. The 0.1 mm deeper dent with IDP is a small effect from probably other than mixing.

The dents from AP and its mixtures were much less than those from HMX, but still significantly more than the 1.70 mm depth from inert samples [8]. Unlike the more shock reactive HMX, filling the pores in AP with HTPB reduced its dent; but, adding Al to porous AP increased the dent, similar to the effect Price et al. [1] had observed on D.

CONTRIBUTION OF AL REACTION IN LARGER SCALE TESTS

Bernecker studied the contribution of Al to shock reactivity by comparing measurements from PBXW-108, which is RDX in a plasticized HTPB binder, and PBXN-109, in which Al replaces some of the RDX. Unconfined samples ranging from 38.1 to 50.8 mm in diameter were shock loaded by a large-scale gap test (LSGT) donor. Streak camera measurements of run distance to detonation (x) were compared [9,10] with those from wedge tests. Data from Figure 3 of reference 9 were scaled and redrawn below, also as Figure 3. The wedge test measurement of x at a given shock pressure in the explosive (P_E) for both compositions is always less than that in the gap test due to the absence of rarefactions in the timeframe of the measurements. Also, x is measured on the lateral surface of the sample in a gap test, which may be somewhat beyond the internal location for the onset of detonation, whereas x in the wedge test is equivalent to an internal location for the onset of detonation.

At the higher shock pressures for each composition, the slope of 1/x versus P_E from gap tests is comparable to that slope from wedge tests. The PBXW-108 data have a somewhat higher slope than that for PBXN-109 at these shock pressures, meaning that an increase in shock pressure reduces the run distance to detonation more so in PBXW-108. At the lower shock pressures, P_E <6.0 GPa, the PBXN-109 gap test data have a higher slope, now the same as for PBXW-108. This slope break for the PBXN-109 does not appear in the wedge test data.

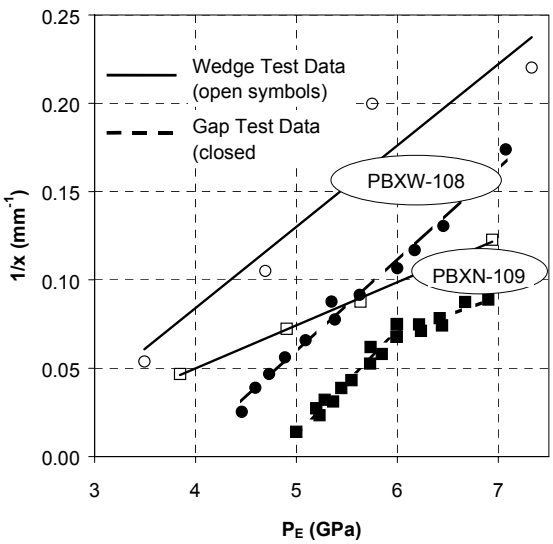

Figure 3. Run distance to detonation in gap and wedge tests for PBXW-108 and PBXN-109 from Figure 3 of Reference 9.

Bernecker made the following conclusion [9] about Al reaction in PBXN-109. "In the PMMA arrangement [LSGT], the aluminum apparently only reacts above 6.0 GPa. Moreover, in this pressure range the data appear to indicate that the participation of aluminum slows down the RDX kinetics." PBXN-109 has similar proportions of ingredients as the SSRT samples in Fig. 2 that were 80/20 HMX/Al blends mixed with HTPB or IDP. Since these samples indicate little Al reaction and HMX has the same oxygen balance as RDX, little of the Al probably reacts in PBXN-109 at high P_E. Thus, an alternative interpretation of Bernecker's data is that there is little Al reaction at high P_E and that the reduced amount of RDX in PBXN-109 relative to PBXW-108 results in less slope (lower shock reactivity) in the 1/x versus P_E plane.

In the pressure range <6.0 GPa, Bernecker addressed [10] the effect of lateral rarefactions on the PBXN-109 gap test. "The presence of two linear regions may be associated, in part, with the radial pressure profiles provided by the 2-D [two-dimensional] shock loading of the pentolite/PMMA system." Less RDX in PBXN-109 requires a larger d_c, and so shock buildup is more quickly quenched by rarefactions, as shown by the higher slope in the lower range of P_E. At these lower pressures for shock initiation, Al reaction is even less likely.

CONCLUSIONS

Adding Al enhanced the reaction of porous HMX and AP in the SSRT, peaking in the range of 10 to 15 %wt. When adding a liquid to HMX/Al mixtures, there was little if any enhancement from the Al. These results are in agreement with the literature, indicating that the SSRT can be useful for studying variations in the major ingredients of formulations.

Bernecker's gap test data for RDX-based compositions with and without Al can be interpreted differently assuming that shock initiation is simply dependent on the RDX concentration and that the Al does not contribute. The Al may not even contribute at the higher shock pressures associated with the detonation wave.

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